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THE PSAMMOCHARIDAE OF THE PHILIPPINES.

By NATHAN BANKS.

THE PSAMMOCHARIDAE OF THE PHILIPPINES.

BY NATHAN BANKS.

SOME years before his death the late C. F. Baker asked the writer to work out the Psammocharidae that he had collected in the Philippines. Later I accepted, but before he could ship the material he died and his collection was sent to the U. S. National Museum. Part of it had already been sent to Mr. S. A. Rohwer. Agreeable to Mr. Baker's request this material has been sent to me for study. The main set, with the uniques and holotypes is returned to the National Museum. Aside from this material I have had little but that collected by Mr. C. S. Clagg in southern Mindanao, mostly on Mt. Apo.

In this paper are recorded 134 species arranged in 46 genera. These are distributed in the various subfamilies as follows: In the Cryptocheilinae four genera and twenty-eight species; in the Macromerinae twenty-two genera and sixty-two species; in the Psammocharinae seventeen genera and thirty-nine species; in the Notocyphinae one genus and two species, and in the Ceratopalinae two genera and five species. One of the most notable finds is a genus of Notocyphinae, as the subfamily was previously known only from the Neotropic region. This form is very remarkable in that there are numerous minute spines on the under side of the mid and hind femora; I have, however, noted that there are similar spines on a Brazilian species of Notocyphus. One of the most characteristic elements of this Malay fauna is the Macromerini, a tribe not known in Africa, America, nor Australia.

A number of genera are found in various parts of the Old World and not in America; such are *Homonotus*, *Platyderes*, *Cyphononyx*, *Ferreola*, *Monodontonyx*, *Tachypompilus*, and *Paracyphonyx*. *Hemipepis* is common in much of the Old World, but a few species are known from America. The typical American genus, *Pepsis*, is unknown in the Old World. Several genera, such as *Batazonus*, *Episyron*, *Anoplius*, *Psammochares*, *Pseudagenia*, and *Priocnemis* are found in all parts of the world.

Within the Malay region we know too little of the fauna of the various islands to make any generalizations. Evidently there is a set of species found in the lowland areas of much of the Malay region, but, so far, there is no indication of the species from the higher regions connecting to the highlands of the Asiatic continent.

Very few species of this family have been recorded from the Philippines. The old authors had but two or three. Ashmead, Rohwer, and Williams in recent times have added about twenty. Likewise but few species have been recorded from either Java or Sumatra, but over seventy years ago Frederick Smith described the material collected by Alfred Wallace, mainly from Borneo and Celebes. Cameron has added many species from Borneo. A few of these I have identified from the Philippines, and have also recognized some of the species known from India. I have included some species from Sandakan, Borneo, since these are closely related to those of Mindanao.

One of the most curious phenomena in the Psammocharidae is the fact that species of various genera, or of different sections of a large genus, are marked precisely the same. I have noted this in *Pepsis*, and Arnold in the African species. It is one of the most remarkable facts in the Philippine species, and since the older authors often described little but color, their descriptions will fit several utterly different species. For example in the *Pseudageninae* nearly all species are black, but there is a species with black head and abdomen and red thorax in four different genera, *Priocnemis*, *Pseudagenia*, *Meragenia*, and *Conagenia*, all so closely similar that in a preliminary sorting they are sure to be lumped together.

Another set are species in *Hemipepsis*, *Cyphononyx*, and *Monodontonyx* with black body, yellowish wings, legs black on base, the rest yellowish, and yellowish hair on head and thoracic notum.

Still another set are the black iridescent-winged species of *Macromeris* and *Cyphononyx*.

Another set is formed of black-bodied, black-winged species with the pronotum reddish.

And another with black bodies, clear wings with a distinct dark stigmal band.

It seems difficult to find a plausible explanation of this similarity of coloring. It certainly is not due to mimicry nor Mullerian association. It would seem that in this family nature is in some way restricted to a few patterns, and uses each pattern in nearly every genus. About fifteen or twenty types of coloring would cover the great majority of species. The most common coloring, and probably the basic, is entirely black.

In the following classification of subfamilies I have put much emphasis on the condition of the under side of the last tarsal joint. In the primitive forms the spines form a row on each lateral edge,

sometimes a few in the middle surface, in the more specialized forms the lateral row is gone (except one at tip) and the under surface is either smooth or with some spines in the middle area. By this arrangement Priocnemis is brought near Pseudagenia, which is also justified by the palpi, and in the eastern United States there are at least two species of which the females are typical Priocnemis and the evident male a typical Pseudagenia as far as the spines on hind tibia would place it. I have restricted the Pepsinae to the old genus Pepsis. This genus differs strongly from the Cryptocheilinae in possessing many primitive characters. The hind wing is very broad, and thus the anal cell is much larger and longer than in other Psammocharidae; the head is very thick behind, the legs densely clothed with spines, and particularly the upper side of the last tarsal joint bears spines, as well as the under side; in all other members of the family this joint has but bristles or hairs above, often bare.

I have not separated as of great value those forms with a long pronotum; an examination of the male of *Cryptocheilus discolor* does not encourage one to place prime value on pronotal differences as characterizing large groups.

In considering the relation and separation of groups it is useful to note the lines along which specialization has proceeded in the evolution of these groups. As in many insects there has been progress in the narrowing of the base of the hind wing, this has made the anal cell not only shorter but has also narrowed it, so that the evanescent vein which is near the middle of the cell in Pepsis is gradually brought nearer and nearer to the anal vein, until in Homonotus it has nearly vanished. With this goes the lessening in the size of the anal lobe. Progress has also been in the thinning of the thick head of Pepsis until in some Psammocharinae and Homonotus the occiput is a deep cavity. Progress has also been in solidifying the trochanters to the femora; very distinctly separate in Pepsis, in Homonotus the trochanters are scarcely distinguishable from the femora. Progress has been in moving the furrow of the second ventral segment; in Pepsis near the middle, it gradually gets nearer to the front margin of that segment, until it is obliterated in one sex of Pseudagenia, and in both sexes of most of the Psammocharinae. Progress has been especially noticeable in the reduction of the spines so thickly set on the legs of Pepsis until in some of the higher forms there are almost no spines. Moreover with this reduction in number there is an increasing constancy in number and position of spines. Progress has been from the wide disjunction of the basal and transverse vein until

they are almost aligned. Progress has been in the obliteration of the pleating of the apical margin of the wings. Likewise in the obliteration of the scar in the base of the first discoidal cell. There is progress in the shortening of the first submarginal cell.

Synopsis of Subfamilies.

1. Last joint of all tarsi beneath with at least a few distinctly lateral spines; hind tibiae of female spined or toothed, or both above; second ventral segment with a transverse furrow; spines at tips of tibiae more or less subequal and parallel; tarsi very densely spined; femur without spines at tip; never a true comb to front tarsi..... 2
 Last joint of all tarsi beneath smooth, or with spines only on the median surface, none laterally; hind tibia of female sometimes with few or only very small spines; front tarsi of female sometimes with a comb of spines..... 3
2. Last joint of hind tarsus with distinct spines on upper surface; hind wings broad, the anal vein ends far beyond cubital fork, about as far as width of anal cell; first recurrent vein ends near the base of the second submarginal cell; marginal cell very long, sides nearly parallel, end blunt; base of second submarginal extends obliquely backward a long distance.....PEPSINAE
 Last joint of hind tarsus without distinct spines on upper surface; hind wings less broad, the anal vein ends near to the cubital fork, never very far beyond; first recurrent rarely, if ever, ends near base of second submarginal cell; last few joints of maxillary palpi usually somewhat thickened at tip, never greatly elongate; hind tibiae are serrately toothed, or spined, or with a carina.....CRYPTOCHEILINAE
3. Entire labrum free, and bent at slight angle beneath the clypeus; propodeum without an elevated hind border; hind tibiae with only very short spines..... 4
 Labrum only partly exposed at most, projecting from below the edge of the clypeus; a raised border at end of the propodeum..... 5
4. Eyes emarginate within; a suture on each side of mesosternum in front of mid coxae; spiracle on propodeum hardly its length from base; tarsi with only a few spines along middle of under sides.. CERATOPALINAE
 Eyes not emarginate within; no such sutures on the mesosternum; spiracle on the propodeum more than its length from base; the middle row of spines under tarsi is very dense; lower pronotal lobes broad at tip..... NOTOCYPHINAE
5. Second discoidal cell with a pocket in the lower basal corner; lower side of pronotum ends in a broad lobe; femur often with one or more spines at the tip, often a comb of spines on the front tarsus of female; hind tibia with moderate to long spines, never serrately toothed; the spines at tips of tibiae unequal and divergent; second ventral segment rarely with a transverse depression.....PSAMMOCHARINAE

Second discoidal cell without a pocket in the lower basal corner; lower side of pronotum ends in a narrow or pointed lobe; femur never with spines at tip; no comb to front tarsus; hind tibiae serrately spined, or with the spines extremely weak or absent; maxillary palpi with the last three joints usually very slender and elongate; spines at tips of tibiae subparallel, usually small or obsolete. MACROMERINAE

CRYPTOCHEILINAE.

1. Base of second submarginal cell is very oblique and extends before the long stigma, latter very long and with nearly parallel sides; the marginal cell long, its base nearly truncate, tip sometimes blunt; a spot or scar in the base of the first discoidal cell; in hind wings the anal usually ends beyond the cubital fork; claws usually with two or more teeth, the basal sometimes weak, antennae short, the last joint usually much shorter than the first; first recurrent vein always ends at or very close to the end of the second submarginal cell. .HEMIPSEPSINI
Base of second submarginal cell never very oblique; first recurrent rarely ends at or close to the tip of the second submarginal cell; stigma not long and parallel-sided; marginal cell usually pointed at tip, and oblique (not truncate) at base; antennae slender, slender toward tip, last joint elongate. CRYPTOCHEILINI

Synopsis of Genera.

1. Base of second submarginal cell very oblique; stigma elongate, with parallel sides; marginal cell truncate (or nearly so) at base, and scarcely pointed at tip; first recurrent ends at or near the end of the second submarginal cell; usually a spot or scar in the base of the first discoidal cell; in hind wing the anal ends much beyond cubital fork; labrum (♀) usually notched in middle; claws usually with two teeth, but the basal one sometimes small or obsolete.*Hemipepsis*
Base of second submarginal cell not very oblique; stigma shorter, and more rounded below; marginal cell more pointed at base as well as at tip; no scar in base of second discoidal cell; claws not with two teeth. 2
2. Claws cleft in both sexes; femora usually with some fine hair; labrum not notched; antennae slender.*Cyphononyx*
Claws toothed, at least in females; males sometimes with cleft claws. . . 3
3. The sides of mesonotum not or but little reflexed; claws of both sexes toothed.*Cryptocheilus*
The sides of mesonotum sharply reflexed; claws of male cleft, of female toothed. 4
4. Lower side of second discoidal cell ends on the median cross-vein nearer to the median than to the cubital vein; head, seen from side, shows the antennae nearer to vertex than to lower edge of clypeus; last joint of tarsi with stiff bristle above.*Parasalius*

Lower side of second discoidal ends at least as near to the cubital as to the median vein; head, from side, shows the antennae as near to lower edge of clypeus as to vertex. *Monodontonyx*

HEMIPEPSIS.

Females.

1. Pro- and mesonotum black with wholly black pile, face usually wholly black. 2
Pro- and mesonotum more or less yellowish or with yellowish pile; face more or less yellowish, labrum usually notched. 5
2. Fore wings with a whitish band, or largely yellowish in middle; thorax very high. 3
Wings wholly black or dark, antennae mostly yellowish. 4
3. Fore wings with broad whitish spot beyond the middle, antennae yellowish. *ducalis*
Fore wings largely yellow brown, black on base and tip (*Moropepsis*) *croesus*
4. Labrum entire; wings wholly black; legs (except most of femora) yellowish. *negritos*
Labrum notched; wings paler toward tip; legs wholly black; large species. *momentosus*
5. Wings (except tip) wholly fulvous. 6
Wings more or less black or brown. 7
6. Propodeum and pleura black. *fulvipennis*
Propodeum and pleura yellowish. *bakeri*
7. Abdomen and thorax yellowish. 8
Abdomen and most of thorax black or brown; wings deeper brown or black. 9
8. Mesonotum with dark streak each side; carina on hind tibia broken into teeth. *luzonica*
Mesonotum not dark on each side; carina on hind tibia not plainly broken into teeth. *dubitans*
9. Second plus third antennal joints scarcely equal to vertex width; carina of hind tibia undulate along edge; very small species. *excepta*
Second plus third antennal joints more than equal vertex width. 10
10. Carina on hind tibia not divided into teeth, large species. *tagala*
Carina on hind tibia broken into teeth. *minora*

Males.

1. Pro- and mesonotum black and with black pile. 2
Pro- and mesonotum partly yellow or with yellowish pile. 4
2. Antennae black; wings yellowish brown except broadly black at tip and base. *croesus*
Antennae yellowish. 3

3. Fore wings with a large white band across beyond middle.....*ducalis*
No such pale area, smaller species.....*negritos*
4. Abdomen almost wholly black..... 5
Abdomen largely ferrugineous or yellowish..... 6
5. Wings black or dark brown.....*tagala*
Wings almost wholly yellowish.....*bakeri*
6. Wings uniformly brownish; coxae and pleura black; small species...*excepta*
Wings darker near tip or wholly pale..... 7
7. Coxae and pleura black; large species; first recurrent at end of second
submarginal.....*fulvipennis*
Coxae and pleurae yellowish, first recurrent ends much before end
of second submarginal cell..... 8
8. Pregenital ventral segment with a nearly even ridge each side ending
in a curved black hook; often a dark streak each side on mesonotum,
apex of wings usually not very dark.....*luzonica*
Pregenital ventral segment with a short ridge each side which is
greatly elevated before the apical black hook; apex of wings very
plainly dark; rarely (if ever) with dark streaks on mesonotum....*dubilans*

Hemipepsis croesus sp. nov.

♀ Black on body, antennae, and legs; wings black at base and fairly broadly at tip, between the two, yellowish. Head and thorax with black pile. Head small for size of thorax, which is very high; labrum entire; clypeus truncate in front; anterior ocellus larger than the posteriors, latter almost twice as near to each other as to eyes; antennae very short, third joint one and two-thirds as long as the fourth, and longer than vertex width, which is wider than usual, the face not as much narrowed above; pronotum deeply arcuate behind; mesonotum with one bristle each side in front; a short median ridge on the posterior part of the mesonotum; propodeum with strong, complete carinae, the posterior slope smooth, all over with long black hair; pleura also with fine long black hair; abdomen convex, tip bristly, a few hairs on vertex; coxae hairy, front coxae also hairy behind, no bristles under front femora, long spur of hind tibia hardly one-fourth of the basitarsus, last joint of hind tarsus much longer than third, nearly equal to second; hind-tibia above with an even carina, no inner row of spines, but the usual outer row. Marginal cell of forewings very long, rounded at tip, extending a little beyond the third submarginal, latter hardly twice as long as broad, not quite as long as the second; second recurrent but little curved, and ends at second fifth of the third submarginal cell; the basal and transverse veins are nearer to the base of wing than in the other species, almost

before the end of the first third; in hind wing the anal is much beyond the cubital fork, the evanescent vein very indistinct and crosses the anal at about middle. Length 43 mm; forewing 40 mm.

Sandakan, Borneo; Isl. Biliran; Isl. Samar; Isl. Sibuyan, Cuernos Mts., Negros; and Surigao, Mindanao. Although possessing the characters of the genus, it is quite different from the others, and I shall call it a subgenus, *Moropepsis*, because of the very high thorax, the hind tibia lacking the inner row of spines, and the basal position of the basal vein, which elongates both the first and second discoidal cells.

Hemipepsis ducalis Smith.

One male from Sandakan, Borneo. Black; face brown; basal joint of antenna brown, beyond ferrugineous; fore wings with a large white band beyond the middle. Clypeus truncate below; labrum with faint indication of a notch in middle; antennae thick, rather short, scarcely crenulate toward tip, fourth joint not three times as long as broad; pronotum deeply arcuate behind; propodeum strongly transversely wrinkled; pleura with dense black hair as long as that on head; legs with short stout spines, long spur of hind tibia not quite one-half of the basitarsus; hind tibia above without any definite carina and with one row of short spines; genital plate broadly rounded, preceding segment with a high carina each side, about two-thirds the width of genital plate apart, the space between them slightly concave. Fore wings with basal veins about two-fifths way out; marginal cell long, tip rounded, base truncate; third submarginal not twice as long as broad, narrowed but little above, receiving the second recurrent vein before end of basal third. I suppose that this is the *Pepsis diselene* Smith (B. M. Cat. 200) but Bingham says nothing of it. Enderlein (Stett. Zeit. 1901, 152) puts it in *Salix*.

Hemipepsis momentosa Smith.

A female from Calian, Mindanao, has the antennae largely yellow as noted by Schulz; his specimens were from Palawan. Smith made no statement of antennae, which may have been broken in the type. Schulz has given a description; in my specimen there is a very fine pale line by the middle of each orbit; the postscutellum is ferrugineous as noted by Smith, the basal joints of antennae are black, beyond yellowish, but several near tip are partly infuscated; the wings are nearly black at base and become paler toward tip, where they are very

pale. The pro- and mesonotum have short, dense black pile, and there are about three erect bristles each side on the anterior part of the mesonotum; the front femora have a few bristles below. The hind tibia has a carina, which is notched almost to form teeth; there is an inner and outer row of short spines, the inner row much less numerous than the divisions of the carina; long spur of hind tibia scarcely one-fourth of the basitarsus.

Hemiopsis bakeri sp. nov.

♀ The head, pronotum, and mesonotum are clothed with the same golden pile as in *H. fulvipennis*, the abdomen black, the entire thorax, pleura, legs, and antennae entirely yellowish; the mesosternum darkened in middle; the wings nearly as deeply ferruginous as in *H. fulvipennis*, the apex narrowly darkened. The labrum is emarginate in the middle, the clypeus truncate, the bristles confined to a row of four; ocelli large, posteriors about as close to each other as to eyes; third antennal joint not as elongate as in *H. fulvipennis*, second plus third hardly more than vertex width; pronotum deeply arcuate behind; mesonotum with one long bristle each side in front; propodeum with short hairs, with about twelve strong carinae, which are complete; posterior slope with minute striae; abdomen with bristly tip, and a few hairs on venter; all coxae with a few hairs, and a few under front femora, long spur of hind tibia about two-fifths of the basitarsus; hind tibia above with a low carina, mostly broken up into teeth, the inner row of spines close to these teeth, the outer row remote as usual. In the forewings the marginal cell is not acute at tip, the third submarginal is a little more than twice as long as broad, about as long as the second, the second recurrent vein ends a little before middle of the third submarginal cell; in the hind wings the anal ends plainly beyond the cubital fork, and the evanescent vein crosses a little beyond middle of anal.

The male is marked in the same way, the dark tip of wings a little broader; the abdomen is more fusiform, and depressed near base; the joints of antennae near tip are narrowed at base and tip, other joints even, the fourth about three times longer than broad; the hind tibia has no carina above, only the two rows of short spines, long spur of hind tibia fully one-half basitarsus. Length 15 to 19 mm., fore wing 14 to 16 mm., ♂ length 14 to 16 mm.

From Mt. Makeling, Luzon; Limay, Bataan; Tangeolan, Bukidnon; Davao, Kolambugan, Dapitan, Iligan, and Cagayan in Mindanao.

Hemipepsis negritos sp. nov.

♀ Black, the antennae, and the legs from the apical part of the femora are yellowish, both wings violaceous black; head and thorax with a very short black pile; abdomen shining. Labrum entire; clypeus truncate below, with a few bristles on the lower part, fine hairs on vertex; anterior ocellus much larger than the posteriors, the latter a little nearer to each other than to the eyes; third antennal joint moderately elongate, about as long as vertex width; pronotum almost angulate behind; mesonotum with one bristle each side in front; propodeum with complete carinae all over, those on the posterior slope are finer and closer together; abdomen convex, apex bristly, very few hairs on the venter; all coxae with some hairs, mostly short, and a few short ones under the basal part of front femora; long spur of the hind tibia about two-fifths of the basitarsus; hind tibia without a carina above, only the two rows of short spines, and some on lower outer side. In fore wings the marginal cell is not pointed at tip; the third submarginal cell is about twice as long as high, its outer side much narrowed above, almost as long as the second, the second recurrent vein slightly curved, ending a trifle beyond the basal third of the third submarginal cell. In hind wings the anal ends plainly beyond the cubital fork, and the evanescent vein crosses the anal a little beyond middle. The male is the same in color; the antennae strongly crenulate (except on base); the posterior ocelli nearer to each other than to the eyes; the propodeum is hairy, but without carinae, the hind tibia has two rows of very short spines above, the long spur of hind tibia is about two-thirds of the basitarsus; venation as in the female. Length ♀ 19 mm., fore wing 17 mm.; length ♂ 12 mm.

From Surigao, Butuan, Iligan, and Kolambugan, Mindanao; Island of Samar; Cuernos Mts., Negros; Island of Sibuyan.

Hemipepsis minora sp. nov.

♀ Color and markings as in *H. tagala* Gribodo; lip, clypeus, and antennae as in that species; ocelli large, but vertex is narrower so that the posterior ocelli are plainly nearer to the eyes than to each other; pronotum arcuate behind; mesonotum with one bristle each side in front, the pile forming a crest as in *H. tagala*; propodeum with short, fine hair, the carinae complete, posterior slope with one or two carinae on upper part; the carina separating the two parts not as prominent on sides as in *H. tagala*; all coxae hairy, front femora with a few bristles beneath; long spur of hind tibia two-fifths of basitarsus;

the hind tibia with a carina above, which is divided into distinct teeth (about twelve), an inner and an outer row of short spines, and some on lower outer side. In the fore wings the marginal cell is not as long as in *H. tagala*, its tip much more pointed; the third submarginal cell a little more than twice as long as broad, scarcely longer than the second submarginal; the second recurrent strongly curved, and ends at basal third of the third submarginal cell; in hind wings the anal ends scarcely beyond the cubital fork, and the evanescent veins crosses the anal almost at middle. Length 15 mm., fore wing 14 mm.

From Culasi, Panay, June (McGregor); N. W. Panay, and Mt. Banahao, Luzon. Differs from *H. tagala* by much smaller size, by the carina on hind tibia broken into teeth, longer spurs to hind tibia, shorter marginal cell, etc.

Hemipepsis tagala Gribodo.

This species is marked just as in *Salix bipartitus*, but it is larger. The labrum is emarginate; the clypeus truncate below, the bristles on lower part; the ocelli are large, the anterior one hardly its diameter from the posteriors, the latter usually a little nearer to each other than to eyes; third antennal joint very long, longer than vertex width; pronotum scarcely angulate behind; the mesonotum with about three long bristles in row each side, the pile here and on the scutellum tends to form a median ridge; propodeum with the carinae coarse and somewhat complete, somewhat irregular, posterior slope often with some carinae, hairs as usual; abdomen with many bristles near tip, and on each ventral segment; all coxae hairy, and a few under basal part of front femora; long spur of hind tibia not one-third of the basitarsus; hind tibia above with a slightly crenulate carina, not forming teeth, an inner and an outer row of spines, and a few on lower outer side. In fore wings the marginal cell is blunt at tip, extending out as far as the third submarginal cell, this cell is nearly twice as long as broad near tip, scarcely longer than the second submarginal; the second recurrent vein is curved, and ends before middle of the third submarginal. In hind wings, the anal ends a little beyond the cubital fork, and the evanescent vein crosses the anal a little beyond the middle of anal cell. The male is similar, but more slender; there is a large black mark over vertex, extending down to the antennae; the dark stripes on mesothorax are very distinct and connected across front; the ridges on the propodeum are rather smaller than in the

female; the antennal joints are scarcely smaller at ends, most of the joints fully three times as long as broad; on the hind tibia above there is no carina, only the two rows of spines, the long spur of hind tibia more than one-half of basitarsus. In color similar to *H. consanguineus* of India, in that species the abdomen is largely yellowish, and the clypeus emarginate below.

From Mt. Banahao Luzon; Island of Samar; Cuernos Mts., Negros; Butuan and Zamboanga, Mindanao.

Hemipepsis fulvipennis Fabr.

The same type of markings occurs in three genera, but this one with the characters of *Hemipepsis* is considered the Fabrician species. The labrum is plainly emarginate in the middle; the clypeus truncate below, bristles only on the lower part; the ocelli of good size, the posteriors scarcely nearer to each other than to the eyes; third antennal joint much longer than fourth and equal to the vertex width; the pronotum somewhat angulate behind; the golden pile on mesonotum and scutellum tends to form a median ridge, one or two long bristles each side on anterior part of mesonotum; propodeum with the carinae complete (that is extending down on sides to the suture), fairly regular, the posterior surface smooth, rarely with a trace of carinae, hairy as usual; abdomen with numerous stiff bristles near tip, and a few hairs on venter; all coxae with some hairs, a few below on front femora; long spur of hind tibia only a little more than one-third of basitarsus. The hind tibia has a low crenulate carina above, not forming teeth, an inner and an outer row of short spines, and a few on lower outer side. In fore wing the marginal cell is out as far as third submarginal, its tip scarcely pointed; the second recurrent is strongly sinuous and ends at first third of the third submarginal cell, this cell is longer than the second submarginal, about two and a fourth times as long as broad near tip; in hind wings the anal ends a little beyond the cubital fork, and the evanescent vein crosses the anal a little before the middle. Length 20 to 28 mm.

Females from Mt. Makeling, Luzon; Island of Samar; Dapitan, Iligan, and Kolambugan in Mindanao; and also from Sandakan, Borneo.

♂ Face yellowish, more or less blackened on front near ocelli; antennae ferruginous, more brown on basal half above; pronotum yellowish behind; mesonotum largely brown; scutelli yellowish; propodeum and pleura black; abdomen dark ferruginous; legs (ex-

cept black coxae) ferrugineous; wings brown on apical part, fading into the paler yellowish basal part; head and thorax with only rather short hair, but longer on propodeum. Clypeus almost truncate (faintly rounded) below; anterior ocellus larger than others, posteriors about as near eyes as to each other; antennae crenulate toward tip; pronotum deeply arcuate behind; scutelli faintly crested; propodeum evenly arched, transversely carinate; abdomen rather short, narrow, basal segment much narrowed at base and above somewhat flattened, venter with much short fine hair. Legs slender, tibiae and tarsi with spines, hind tibia with two rows of spines above, no carina, long spur of hind tibia over one-half of basitarsus. Fore wings with marginal cell long, apex hardly pointed, base truncate; third submarginal cell about twice as long as broad, receiving the second recurrent vein at basal third; first recurrent ends at end of second submarginal; in hind wings the anal ends plainly beyond the cubital fork. Length 15 to 23 mm. From Los Banos, Luzon; Dapitan, Iligan, and Kolambugan in Mindanao.

Hemipepsis excepta sp. nov.

♀ Head, pro- and mesonotum and the scutelli with yellowish pile, elsewhere body dark brown; antennae and legs (except coxae) yellowish; wings brown. Clypeus truncate below, with a row of four bristles; labrum faintly indented in middle; anterior ocellus larger than the others, posteriors rather nearer to eyes than to each other; antennae short, third joint but little longer than the fourth, and the second plus third not equal to vertex width; hind margin of pronotum arcuate; propodeum nearly evenly arched, finely carinate on the basal part, apical slope nearly smooth; abdomen polished, convex, yellowish hairs close to tip, few on venter; legs rather short, tibiae and tarsi spined, hind tibia with the carina crenulate, almost into teeth, an inner and outer row of spines; long spur of hind tibia about one-half of basitarsus. Fore wings with a long stigma, marginal cell rather long, hardly acute at tip, third submarginal almost twice as long as broad, receiving the second recurrent a little beyond basal third; in the hind wing the anal ends just beyond the cubital fork. Length 13 mm., fore wing 12 mm.

From Mt. Makeling, Luzon.

♂ Head yellowish, above antennae with a large blackish spot, connected to the black around ocelli; antennae yellowish; posterior part of pronotum and the tegulae yellowish, rest of thorax and coxae

black; the abdomen reddish, except basal segment partly blackish; legs yellowish; wings dark brown, uniform. Labrum entire, clypeus faintly emarginate below, the pit each side above clypeus more prominent than usual; ocelli subequal, the posteriors about as near eyes as to each other; antennae somewhat crenulate on apical part, third joint about three times as long as broad, but little longer than the fourth; pronotum behind deeply arcuate; propodeum low, the striae are not very strong; abdomen convex, slightly hairy on venter; legs rather slender, the mid and hind tibiae and tarsi with very short spines, those above on hind tibia form two rows, no carina; long spur of hind tibia nearly two-thirds of basitarsus. Fore wings with the marginal cell long, sides parallel, tip not acute; stigma elongate, sides parallel; third submarginal cell more than twice as long as broad, outer side rounded; second submarginal scarcely shorter below, very narrow; first recurrent vein ends a trifle before end of the second submarginal; second recurrent scarcely sinuate, ends a little before the middle of the third submarginal; hind wings have the anal cell ending at the cubital fork. Length ♂ 12 to 14 mm., fore wings 11 to 13 mm.

From Mt. Makeling, Luzon.

Hemipepsis luzonica sp. nov.

♀ Yellowish throughout, a dark band across front of mesonotum; head, pronotum, and mesonotum with golden pile, on latter parts forming a median crest; wings brown, almost yellowish brown; some dark brown on the mesosternum. Labrum emarginate in middle; clypeus truncate below, bristles on lower part, some long hairs near vertex; anterior ocellus plainly larger than posteriors, latter much nearer to each other than to eyes; third joint of antennae not one-half longer than fourth, second plus third not equal to vertex width; pronotum arcuate behind; mesonotum with one bristle each side in front; propodeum low, almost flat, weakly transversely ridged, the carinae not quite reaching to suture on lower sides, posterior slope with a few carinae; abdomen convex, tip with many yellow brown bristles, very few hairs on venter; coxae with short hairs, front coxae with some long bristles, and two or three on base of front femur beneath; long spur of hind tibia almost one-half of basitarsus; hind tibia above with a low carina, strongly crenulate, but no sharp pointed teeth, a row of short spines each side. In fore wings marginal cell pointed at tip, extending beyond third submarginal; latter not

twice as long as broad near tip, but a little longer than second; second recurrent ends before basal third of the third submarginal; in hind wings anal scarcely beyond the cubital fork, evanescent vein crossing at about middle of anal. Length 15 to 17 mm., fore wing 14 to 16 mm.

From Mt. Makeling and Los Banos, Luzon; and Iligan and Zamboanga, Mindanao.

♂ Body, legs, and antennae pale yellowish; wings pale yellowish, except usually a dark cloud at tip. Often there is a dark triangle on vertex extending toward antennae, and sometimes a dark brown streak each side on the mesonotum, widest in front; abdomen sometimes brownish, and the basal segment at base black. Clypeus broadly evenly rounded below; ocelli subequal, posteriors nearer to each other than to eyes; antennae crenulate toward tip; pronotum broadly arcuate behind; propodeum very low, nearly flat with much fine pale hair, no evident carinae; abdomen very slender, without hairs; legs slender, tibiae and tarsi with yellowish spines; hind tibiae without a carina, but with two rows of distinct spines, long spur of hind tibia fully two-thirds of the basitarsus; wings slender; first recurrent ends at apical fourth of second submarginal, second recurrent ends at the basal third of the third submarginal, latter about once and a half as long as wide, much narrowed above; marginal cell fairly acute at tip; in hind wings the anal ends beyond the cubital fork. The pregenital plate shows a carina each side of nearly even height tipped by a curved black spine. Length 10 to 13 mm.

From Mt. Makeling and Mt. Banahao, Luzon; from Kolambagan, Davao, in Mindanao; and Island of Sibuyan.

The female might fit the description of *H. ichneumoneus* Guerin, based on a female from New Guinea, except there is no noticeable pale spot in front wing; Bingham's *ichneumoneus* is based on males similar to the males of *luzonica* and *dubitans*, but I doubt if either are males of the true *ichneumoneus*. Smith's description of *H. ferruginea*, based on a female from the island of Dory, agrees fairly well with that of female *luzonica*, but since there appears to be two species in the Philippines, there may well be another on Dory. *H. opulenta* Smith is probably related, but it is said to have the clypeal margin truncate, and the propodeum striated.

Hemipepsis dubitans sp. nov.

♀ Marked as in *H. luzonica* except that there is no dark streak each side on the mesonotum. The only definite structural character I can find to separate it is that the carina on the hind tibia is not

definitely divided into teeth, whereas in *luzonica* the divisions into teeth are quite distinct; the antennae are, perhaps, a little longer. Were it not for the apparent existence of two male forms which evidently must belong to these females I would not separate them. The size runs a little larger. Many specimens from the Island of Samar; also N. W. Panay; Cuernos Mts., Negros; Island of Sibuyan; and from Dapitan, Mindanao; Mt. Makeling, Luzon.

♂ In nearly every way very similar to *H. luzonica*, but the wing is more often embrowned and the dark apical cloud is very distinct and usually larger; there are no dark streaks on the mesonotum. It differs at once in that on the pregenital ventral segment there is no longer even carina each side, but a short one which is greatly elevated in a rounded lobe, with the curved black hook on the lower edge. This difference is so distinct and constant in a series of specimens that I believe it must indicate a separate species, particularly so since in some species in this genus the processes on this segment are practically unmodified. The size is about the same. There are many specimens from the Island of Samar; from Surigao, Butuan, Dapitan in Mindanao; from Mt. Makeling, Luzon; and the Island of Biliran.

CYPHONONYX.

This genus is distinct by the bifid claw of female; the femora are usually provided with some hairs. The species have the same types of coloration as in allied genera.

CYPHONONYX.

Females.

- | | |
|--|----------------------|
| 1. Face more or less yellowish or with yellowish hair..... | 2 |
| Face entirely black, and with black hair..... | 5 |
| 2. Wings wholly yellowish, only a narrow dark margin..... | 3 |
| Wings dark brown or black at least on basal part..... | 6 |
| 3. Clypeus dark, with golden hair; last joint of antennae dark..... | <i>claggi</i> |
| Clypeus yellow, with yellowish hair; last joint of antennae not darkened..... | <i>flava</i> |
| 4. Fore wings yellowish on apical half except a narrow margin, hind wings also partly yellowish; antennae black..... | <i>rizali</i> |
| Both wings wholly black, with brilliant iridescent effulgence..... | 5 |
| 5. Clypeus (♀) plainly emarginate below; body black, without blue reflections..... | <i>fulgipennis</i> |
| Clypeus (♀) truncate below; body, especially the abdomen, with blue reflections..... | <i>pulchripennis</i> |

6. Both wings wholly dark; apical parts of legs yellowish or reddish.
 In female, face wholly yellowish, also pro- and mesonotum... *bipartitus* ♀
 In male, face dark in middle; lobes of pronotum yellowish... *bipartitus* ♂
 Fore wings more or less yellowish..... 7
7. Antennae yellowish (except base); tarsi wholly dark; fore wings with
 large discal pale area; hind wings wholly dark..... *valdezi*
 Antennae black, at least mostly; fore wings with a large median
 yellowish area; hind wings with pale spot in middle... (Singapore) *cameroni*

Cyphononyx flavus Fabr.

Specimens from Iigan and Lawa, Davao Prov., 30 April (Clagg); both are from Mindanao. There is much dispute as to what is the *Sphex flava* of Fabricius. Turner (Ann. Mag. Nat. Hist. (9) V, 97, 1920) admits that the specimen in the Banksian collection is a *Cyphononyx*, and renames it *C. peregrinus* ab. *disjunctus*, claiming that the name *flava* should be used for a *Cryptochilus* (*Priocnemis humbertianus*) with the claws unidentate in both sexes. I doubt if Dahlbom was any more exact than Fabricius himself in comparing these forms, since he records it also from Egypt. The species in the lowlands of Mindanao is probably widely distributed in other lowland Malay localities, and I therefore identify it with what Fabricius himself named and may even be a type. Fabricius did not say in what collection the type was, and in the Banksian collection are types which Fabricius did not state were there (Blair 1920).

The clypeus is truncate below, almost emarginate in middle; a line from the antennae to anterior ocellus; ocelli in a low triangle on a black spot; anterior ocellus rather the larger, posteriors nearer to each other than to the eyes; antennae rather short, third joint a little longer than the fourth, second plus third not equal vertex width; lateral lobes of the pronotum swollen, and with a distinct depression in middle behind; the propodeum with the apical middle part somewhat flattened, a distinct median groove, coarsely rugoso-striate and hairy above; metanotum striate on sides. Abdomen rather short, basal segment densely short haired, several of the segments toward tip and the venter hairy; hind tibiae with a row (about sixteen) of even teeth, and an outer row of spines; long spur of hind tibia about one-third of the basitarsus. In fore wing the marginal cell is rather wider toward tip than toward base; second submarginal cell about one-half longer than broad, base nearly straight, receiving the first recurrent at apical fourth; third submarginal cell longer than the second, narrowed about one-third above, receiving the second recurrent vein

(evenly curved) near middle; in the hind wing the anal ends a little before the cubital fork.

Cyphononyx rizali sp. nov.

♀ Black, with bluish reflections, particularly on the abdomen; wings black on base, fading to brown, and from there out a brownish yellow or tawny, apical margin narrowly dark; hind wings black to brown on basal part, beyond this brownish yellow, with a dark tip, the dark parts more or less violaceous; hind wings fully half black. Clypeus very convex, truncate below; line from anterior ocellus to the antennae; ocelli subequal, posteriors nearer to each other than to the eyes; third joint of antennae one and a half longer than fourth and about equal to vertex width; head densely hairy; pronotum also very hairy and broadly arcuate behind; mesonotum with only short pile, a few long hairs in front; scutelli densely long haired, as also the pleura and propodeum, latter evenly arched, transversely striate; abdomen convex, basal part of basal segment densely long-haired, apex also hairy, and the venter more hairy than usual. Legs with quite a number of long, fine hairs on the femora; the tibia and tarsi with stout spines, claws cleft; hind tibia with two rows of teeth and short spines with them; long spur of hind tibia hardly one-fourth of basitarsus. Wings with very long marginal cell, and blunt at tip; stigma very short; third submarginal fully twice as long as broad, longer than the second; first recurrent ends near tip of the second submarginal cell; second recurrent bent outward and ends beyond basal third of the third submarginal cell; in hind wings the anal cell ends at cubital fork. The male is colored and marked as in the female, but with the tips of wings rather darker and violaceous; the body more slender; the antennae long and slender, third joint plainly longer than the fourth, but not equal to vertex width; hind tibia without teeth, and only very short spines above; long spur of hind tibia fully one third of basitarsus; venation the same. Length ♀ 23 to 30 mm., fore wing 22 to 28 mm., length ♂ 22 mm. From Calian, 29 May (Clagg), Baroring River, Mt. Apo, 7000 ft., 10 Nov. (Clagg), Kolambugan, Butuan, Iligan, Dapitan, and Surigao, all in Mindanao; Mt. Makeling, Los Banos, and Baguio Benguet in Luzon; Malinao, Tayabas, Tanglecolan, Bukidnon; Island of Biliran; Island of Samar; N. W. Panay; and Cuernos Mts., Negros; Island of Basilan.

This agrees fairly well with the description of *Mygymia aspasia* Smith from the Aru Islands, but not recorded north of there. Strand compares his *Salix elatensis* from New Guinea with *aspasia*. Since

the same type of markings occurs in various genera it is quite possible that *aspasia* is a true *Mygimnia* (*Hemipepsis*).

Cyphononyx pulchripennis Smith.

From Puerto Princesa, Palawan; Island of Samar; Los Banos and Mt. Makeling, Luzon; Tangcolan, Bukidnon; and Sandakan, Borneo. The clypeus is truncate below; ocelli subequal, the posteriors nearer to each other than to eyes; third joint of antennae much longer than the fourth, and longer than vertex width; head, pronotum, post-scutellum, pleura, propodeum, and base of abdomen with long black hair; hind tibia above with a row of stout teeth with spines, and an outer row of spines; long spur of hind tibia hardly one-fifth of the basitarsus. In fore wings the stigma is very short, the marginal cell more acute at base than at tip; the third submarginal cell nearly twice as long as broad, narrowed one-third above, scarcely longer than second below; first recurrent vein ends very near to the tip of the second submarginal cell; the second recurrent much curved and ends a little before middle of third submarginal; in hind wing the anal ends at or just before the cubital fork.

Cyphononyx bipartitus Lepel.

From Iligan, Davao, Kolambugan, and Calian 29 May (Clagg) all in Mindanao; and also from Polillo, and Puerto Princesa, Palawan. Bingham has stated that it has cleft claws so the name is placed on a species in this genus, although as far as the original description goes, it might just as well be a *Hemipepsis* or a *Monodontonyx*. The clypeus is faintly concave below; the ocelli small and depressed, the posteriors a little nearer to each other than to eyes; third joint of antennae but little longer than the fourth, second plus third not nearly equal to vertex width; hind tibia has above a row of teeth with spines and an outer row of spines; long spur of hind tibia more than one-third of basitarsus; in fore wing the stigma is short; the marginal cell long and acute at each end, the third submarginal not twice as long as broad, much narrowed above, but longer than the second; first recurrent ends a little before end of the second submarginal, the second recurrent is outcurved and ends a little before middle of third submarginal; in hind wing the anal ends at cubital fork.

Cyphononyx valdezi sp. nov.

♂ Black; clypeus brown, face with a pale orbital streak; antennae yellowish, first joint brown, last three or four joints black; pronotum

with yellow band behind, body and legs black, front tibia pale at extreme base; wings black, violaceous; a faint yellowish, almost hyaline band almost across from behind stigma toward the outer angle of wings; hind wings with a narrow pale line behind the subcosta. Clypeus very convex, slightly and evenly rounded below, with only short hair; head above antennae and behind densely long haired; a line from anterior ocellus to the antennae; ocelli subequal, posteriors much closer to each other than to the eyes; antennae long, not crenulate, the joints elongate, third a little longer than fourth, but second plus third not equal to vertex width; pronotum short, angulate behind, hairy, scutellum and postscutellum elevated and with a median ridge; propodeum very densely hairy, the transverse carinae faint, near base scarcely visible; abdomen somewhat depressed, hairy on base and somewhat on venter; legs slender, femora with some fine hairs, hind tibia with two rows of very short spines above, and others on outer side fully as long; long spur of hind tibia about two-fifths of basitarsus. Fore wing with very small stigma; marginal cell fusiform, pointed at tip; third submarginal cell about one and two-thirds as long as broad, much narrowed above, a little longer than second submarginal; first recurrent ends very close to end of second submarginal, second recurrent bowed outward, ends a little beyond the basal third of third submarginal cell; in hind wings the anal ends at the cubital fork. Length 16 mm., fore wing 16 mm.

From Sandakan, Borneo.

Cyphononyx claggi sp. nov.

♀ Black; antennae yellowish, the last joint blackish; clypeus black, with golden hair; face yellowish, with golden hair; same over posterior part of pronotum and on the mesonotum and scutellum; legs from apical part of femora yellowish, the tarsi darkened at tips of joints; wings yellowish, apex very narrowly dark. Head with much hair, mostly yellowish; clypeus scarcely emarginate below; a line from anterior ocellus to the antennae; ocelli rather close together, subequal, posteriors much nearer to each other than to the eyes; third joint of the antennae a little longer than the fourth, but not near equal to vertex width; pronotum arcuate behind; this and mesonotum with shorter hair than on head; propodeum sloping gently, transversely striate, hairy, base of abdomen, venter, and several segments of abdomen near tip have rather long hair; last segment with short, ferruginous pubescence; hind tibia above with an inner row of teeth with spines,

and an outer row of spines; long spur of hind tibia fully one-third of basitarsus. Wings with moderately long marginal cell, somewhat pointed at tip; stigma short; third submarginal not quite twice as long as broad, much longer than the second; first recurrent ends at or near apical fourth of the second submarginal cell; the second recurrent vein curved out, ends a little before middle of the third submarginal cell. Length 15 mm., fore wing 15 mm.

From Galog River, Mt. Apo, 6,000 ft., 12 Sept., Davao Province, Mindanao (Clagg).

What is probably the male is marked about the same, but the dark apical margin of wings is much broader; the last four joints of antennae, and the last four joints of mid and hind tarsi are black, and all of front tarsi and tip of tibiae black; the face is black above the antennae leaving a pale orbital streak; the posterior part of the pronotum yellowish, but the mesonotum and scutellum dark; the abdomen is hairy all over; the hind tibia have only spines (no teeth) above, and the long spur of hind tibia is almost one-half of basitarsus; the antennae not crenulate. It is a little smaller than the female and comes from Calian, 28 May, Mindanao (Clagg).

PARASALIUS gen. nov.

Seen from the side the antennae are nearer to top of vertex than to the lower margin of clypeus (in *Monodontonyx* nearer to the lower margin of clypeus than to the vertex); the lateral margins of mesonotum sharply reflexed. In the fore wings the lower side of the second discoidal cell meets the median crossvein plainly nearer to the median than to the cubital vein; the median crossvein here is thickened, but no distinct pocket. The last tarsal joint has stiff bristly hairs above, an approximation to the spines of *Pepsis*; the claws have one tooth, which is before the middle, so that the apical part of claw is longer than in *Monodontonyx*.

Type—*Mygymia anthracina* Smith, and includes *M. princeps* Smith, and *P. plutonis* n. sp. from Singapore.

Synopsis of Species.

1. Wings uniformly faintly yellowish brown..... *plutonis*
Wings not uniform in color..... 2
2. Fore wing with a wide faintly yellowish band toward tip..... *princeps*
Fore wing mostly brownish yellow; with a broad black tip reaching
back along the costa..... *anthracina*

Parasalius princeps Smith.

One female from Sandakan, Borneo. Clypeus broadly rounded below; ocelli close together; posteriors much closer to each other than to the eyes; third joint of the antennae equal to vertex width; pronotum arcuate behind; propodeum evenly arched, transversely carinate; the hind tibia above with a row of teeth (nearly 20) with spines and an outer row of spines, the teeth are large, broader and closer together near base, toward tip the teeth become very small; long spur of hind tibia not one-third of the basitarsus; tarsi very densely spined, last joint with stout bristly hairs above. Fore wings with very long fusiform marginal cell, fully as acute at base as at tip; third submarginal cell fully twice as long as broad, narrowed one-fourth above, scarcely longer than the second, first recurrent ends almost at tip of the second submarginal; second recurrent evenly outcurved, ends at basal two-fifths of third submarginal; in hind wing the anal ends at the cubital fork.

Parasalius anthracinus Smith.

I have identified as this species a large *Parasalius* that agrees in coloration and structure with the descriptions of Smith and Bingham; the latter, however, puts it in the section of *Hemipepsis* with two teeth to claws. This specimen surely has but one; it may be that it is not the true *anthracinus*. Its legs are very long and slender, the hind femora about as long as the hind tibiae. It is from Sandakan, Borneo; also Island of Penang, Malacca.

MONODONTONYX.

I consider this a good genus; it is plainly distinct from *Cryptocheilus*, but is closely related to *Cyphononyx*. Under it I have made a new subgenus, *Dinosalius*, for certain forms with an upraised clypeus.

MONODONTONYX.

Females—Synopsis.

1. Face wholly black, only two short lines at inner orbits pale; antennae black, wings reddish yellow.....*gratiosus*
Face more or less plainly yellow, with yellowish or golden pile..... 2
2. Wings wholly dark brown; antennae yellow, pro- and mesonotum with yellowish pile..... 3
Wings yellowish..... 4
3. Ocelli in the sides of a hump, therefore not conspicuous.....*tagalensis*
Ocelli large, prominent, no ocellar hump.....(China) *sinensis*

4. Face yellowish above antennae; clypeus black..... 5
Face and clypeus with yellowish pile..... 6
5. Pro- mesonotum and scutelli with yellow marks; wings very pale yellowish..... *javanus*
No such spots, on thorax; wings brighter yellow..... *flavipennis*
6. Femora mostly black; median cross-vein much thickened in middle. *festivus*
Femora yellowish, median cross-vein not particularly thickened in middle..... 7
7. Fore wing with a large pocket in the lower basal corner of the first discoidal cell..... *anomalus*
Fore wings with only a small pocket in the first discoidal cell. *sericosomus*

Males.

1. Wings wholly dark brown..... *tagalensis*
Wings largely pale..... 2
2. Antennae almost wholly yellow or ferrugineous; no pale spots on notum, but entire notum and face with yellowish pile..... 3
Antennae largely deep black; notum black with pale yellowish spots on mesonotum and scutelli and a band behind on pronotum..... 5
3. Femora partly black; ocelli moderate size; median cross-vein much thickened in middle, no distinct pocket..... *festivus*
Femora yellowish; ocelli large and prominent; antennae yellow; median cross-vein not especially thickened near middle..... 4
4. With a large pocket in lower base of first discoidal cell..... *anomalus*
With only a small pocket..... *sericosomus*
5. Clypeus below strongly broadly concave; no spot on the clypeus, two basal joints of antennae pale above..... 6
Clypeus truncate below, usually with a median dark spot; dark of vertex reaching broadly down to the antennae; basal joints of antennae dark above; dark of wing tip not sharply defined..... *gratiosus*
Clypeus somewhat broadly rounded below; dark of vertex only narrowly extended toward the antennae; dark spot of wing tip very sharply defined; basal joints of antennae dark above..... *approximatus*
6. Wings very pale yellowish, black of vertex not reaching towards antennae..... *javanus*
Wings a bright reddish yellow, black of vertex reaches forward almost to antennae..... *flavipennis*

Monodontonyx festivus sp. nov.

♀ Black; face, clypeus, posterior part of pronotum, mesonotum, scutelli clothed with dense appressed ferrugineous pubescence; antennae yellowish, tip slightly darkened; legs from apical part of femora out are yellowish; wings deep reddish yellow, paler at tips. Clypeus and face with much long, pale hair, similar long hair on

pronotum, anterior part of mesonotum and the scutelli; propodeum and pleura with long black hair, likewise some on coxae; the abdomen toward tip and on venter hairy. Clypeus very convex, truncate in front; ocelli of moderate size, placed on the sides of a slight hump, anterior larger, posterior twice as near to each other as to eyes; third joint of antennae about one-fourth longer than the fourth joint, second plus third about equal to vertex width; pronotum with a median furrow, almost angulate behind; scutelli rounded; propodeum evenly rounded, with a median groove, and rather strongly transversely carinate all over. Abdomen convex, not much narrowed at base, last segment above with ferruginous appressed hair, basal segment with short hair. Legs with tibia and tarsi rather strongly spined, hind tibia above with an inner row of teeth with spines, and an outer row of spines; long spur of hind tibia about one-third of basitarsus. Wings with very short stigma, radial vein arising near middle; marginal cell long, pointed, third submarginal fully twice as long as broad, much narrowed above, much longer than the second submarginal; first recurrent at apical fourth, second recurrent sinuous, ends at basal third of the third submarginal, in hind wing anal ends a little before cubital fork. Length 19 to 20 mm., fore wing 19 to 20 mm.

From Galog River, Mt. Apo, 6000 ft., 8 Sept.; and Mainit River, Mt. Apo, 6000 ft., 2 Sept.; both Mindanao (Clagg); and Island of Samar.

Monodontonyx approximatus sp. nov.

♂ Black. Clypeus yellow below, rufous above, face reddish, a black triangle from vertex over the ocelli reaches nearly to antennae; latter dull blackish; pronotum behind with a pale yellowish band, spot on middle behind of mesonotum and both scutelli also yellowish; legs beyond the apical part of femora yellowish, part of last tarsal joint and the tip of hind tibia dark; wings yellowish, fore wing with apical fourth black, hind wing with cloud in apical part. Clypeus large, convex, truncate below, a line to anterior ocellus; ocelli of moderate size, subequal, posteriors a little nearer to each other than to the eyes; third joint of antennae much longer than fourth, second plus third fully equal to vertex width; face with short fine hair, vertex with longer hair; pronotum short haired, arcuate behind; scutellum rounded, slightly ridged in the middle, postscutellum almost conical, both hairy; propodeum sloping to the tip, transversely carinate, with

long, fine hairs. Abdomen small, convex, basal segment with short hair, venter with longer hair; tibiae and tarsi with very short, fine spines; hind tibia with two rows of spines above, others as long on side and below; long spur of hind tibia not quite one half of basitarsus; claws cleft. Fore wings with the radial vein arising near tip of the moderate stigma, marginal cell fusiform, pointed; third submarginal not twice as long as wide, narrowed nearly one-half above, not longer than the second; first recurrent ends at apical fourth of second submarginal; second recurrent bent outward, ends a little beyond the basal third of the third submarginal cell; in hind wing the anal ends scarcely before cubital fork. Length 13 mm., fore wing 13 mm.

From Sandakan, Borneo.

Monodontonyx tagalensis sp. nov.

♀ Black, head, posterior part of pronotum, mesonotum, and scutelli yellow and with yellow appressed hair; antennae, and legs from apical part of femora out yellowish, tip of abdomen with ferrugineous hair; wings very dark brown. Clypeus truncate below, very hairy, head above with fairly long hair; ocelli very small, the anterior somewhat larger than the posterior but all somewhat sunk in the sides of a hump that occupies the ocellar area (thus ocelli very different from *M. consanguineus*), the posterior ocelli almost twice as near to each other as to eyes; third joint of antennae very much longer than the fourth, second plus third fully equal vertex width; pronotum almost angulate behind; scutellum only a little convex, with long hair behind; pleura and propodeum densely long haired, the propodeum evenly arched, with a median furrow, and transversely carinate; abdomen fusiform, convex, with hair near tip and on venter. Femora without hair, tibia and tarsi fairly heavily spined; hind tibia with an inner row of teeth with spines and an outer row of spines above; long spur of hind tibia not one-third of basitarsus. Wings with short stigma, the radial vein arising near its tip; marginal cell long, pointed at tip; third submarginal twice as long as broad, narrowed above, much longer than the second submarginal; first recurrent vein ends at apical fourth of the second submarginal, second recurrent ends near basal third of the third submarginal; in hind wings the anal ends barely before the cubital fork. Length 18 to 24 mm., fore wing 17 to 23 mm. The male is very similar in color, in one male the vertex has a large greenish triangle nearly reaching to the antennae; latter not crenulate, third joint fully five times as long as broad, somewhat

longer than the fourth, but two plus three does not equal vertex width; hind tibia with two rows of small spines above. Length 16 mm.

From Baguio, Mt. Banahao, and Mt. Makeling, Luzon; and Zamboanga, Mindanao (Gift of B. P. Clark).

Monodontonyx anomalus sp. nov.

♀ Head, pronotum, mesonotum, scutelli and dorsal part of propodeum yellowish, with yellow hair; antennae, legs (except part of coxae) and the last segment also yellowish or ferruginous; tips of antennae in both sexes darkened; wings yellowish throughout, no dark margin. Clypeus strongly convex, lower edge plainly rounded, a row of long bristles below middle; ocelli subequal, posteriors not their diameter from the anterior, and much closer to each other than to the eyes; third joint of antennae plainly longer than the fourth, and equal to vertex width, a few long bristles on and near vertex; pronotum almost angulate behind, with a median furrow; scutellum rounded, with long erect hair; propodeum moderately short, evenly rounded, faintly transversely striate (not near as marked as in *M. sericosomus*), the median line scarcely noticeable, above with fine, moderately long hair; abdomen rather long, convex, hairy near tip and somewhat on venter. Legs rather long, tibiae and tarsi rather heavily spined; hind tibia above with an inner row of large teeth and spines, and an outer row of much smaller teeth with the usual spines; long spur of hind tibia about two-fifths of basitarsus. Wings with fusiform marginal cell, acute at tip, stigma rounded below, the radial vein arising from near middle; third submarginal hardly one and a half times as long as broad, but longer than the second; first recurrent ends at apical fourth of second submarginal; second recurrent but little curved, ends near basal fourth of the third submarginal; second discoidal with a large pocket in the lower corner, with a nearly square bottom; in hind wing the anal ends before the cubital fork. The male is very similar, but much more slender, the face is narrowed so that the ocelli are nearly as close to eyes as to each other; antennae long and slightly crenulate; third joint much longer than vertex width; hind tibia has the two rows of very small spines above, the last joint of tarsus has only two or three lateral spines, most distinct on front pair, the basal segment of abdomen is much narrowed basally. Length ♀ 16 to 20 mm.; fore wings 15 to 20 mm. Length ♂ 15 mm.

From Galog River, Mt. Apo, 6000 ft., 4 Nov. (Clagg) and Todaya

Plateau, Mt. Apo, 5000 ft., 12 Nov. (Clagg), also Butuan, Iligan, and Dapitan, all in Mindanao, and from Mt. Banahao, Luzon.

Differs from *M. sericosomus* by the remarkable pocket in the second discoidal cell, as well as by minor characters.

Monodontonyx sericosomus Smith.

Specimens from Dapitan, Zamboanga, Mindanao; Island of Samar; N. W. Panay; and Sandakan, Borneo. The clypeus is rounded below, with a transverse row of about five bristles; face much narrowed toward vertex; line from antennae does not reach ocelli; ocelli large, subequal, anterior less than diameter from the posterior, latter closer to each other than to eyes; third antennal joint much longer than the fourth, and of itself fully equal to vertex width; pronotum angulate behind; propodeum short, rounded, transversely striated; metanotum not striated on sides; hind tibiae plainly sinuate, with about fifteen teeth in the row; long spur of hind tibia more than one-third of basitarsus; in fore wing the marginal cell fusiform, pointed at each end; second submarginal cell twice as long as broad, base quite oblique, receiving the first recurrent toward tip; third submarginal a little longer than the second, much wider behind, nearly one-half narrowed above, receiving the second recurrent vein (only slightly curved) plainly before middle (beyond basal third); in hind wing the anal vein ends before the cubital fork.

The male is more slender; the clypeus more truncate below; the third antennal joint equal to vertex width; the ocelli and venation similar to female, but the second recurrent vein is more sinuous; the long spur of the hind tibia about one-half of the basitarsus; the tibia above with only a row of rather weak, yellow spines.

DINOSALIUS subgen. nov.

A division of *Monodontonyx*; claws with one tooth in female, in male cleft; mandibles with the upper tooth very large so that it reaches nearly to the tip of the mandibles, the mandibles thus almost bifid, and very broad at this tooth. The clypeus is raised away from the mouth and it is not hairy, but has long bristles below, the edge tends to be somewhat bi-emarginate, but not always distinctly so; otherwise as in *Monodontonyx*. Type, *Monodontonyx javanus* Lep. (*Calicurgus*). The species known to me are separated thus:

1. Face wholly black, wings bright yellowish, no spots on the mesonotum
nor scutelli.....*gratiosus*
- Face mostly yellowish, clypeus black..... 2

2. Antennae black from third joint out. 3
 Antennae yellow, no distinct pale marks on thorax; wings bright
 amber yellowish. *flavipennis*
3. Wings very pale yellowish; third abscissa of radius but little longer
 than fourth. *javanus*
 Wings dark reddish yellow; third abscissa of radius nearly twice as
 long as fourth; third submarginal very large. n. sp. from Java

Monodontonyx (Dinosalius) javanus Lep.

♀ Clypeus black, face and vertex pale yellowish; occiput black; mandibles rufous; antennae black, first and second joints yellow; thorax black, pronotum with yellowish band behind, mesonotum with large median spot behind and the scutelli pale yellowish. Abdomen black, coxae and most of femora black, tips of femora, the tibia and tarsi yellowish; last tarsal joint dark; wings very pale yellowish. Clypeus not hairy, except for the bristles below, lower margin truncate; line to anterior ocelli; ocelli subequal, fairly large, posteriors a little further from eyes than from each other; antennae slender, third joint about one-fourth longer than the fourth, second plus third about equal to vertex width; face and vertex with very fine, erect hairs, not dense; pronotum short haired, angulate behind; mesonotum with some erect bristles each side; propodeum evenly arched, long, pale hairs, a median line, and transversely carinate; abdomen convex, basal segment short haired, apex and venter long haired; tibia and tarsi moderately spined, the hind tibia above with inner row of small teeth with spines, and an outer row of spines, long spur of hind tibia about one-third of basitarsus. Wings with moderate stigma; radial vein arising from near its tip; marginal cell long, pointed; third submarginal about twice as long as broad, narrowed one-half above, much longer than second; first recurrent ends near apical fourth of the second submarginal; second recurrent bent in middle, ends at basal third of the third submarginal; in hind wings the anal ends a little before the cubital fork. Length 18 to 20 mm., fore wing 17 to 19 mm.

From Singapore Malacca, and Sandakan, Borneo. *Priocnemis verticalis* Smith is the same species.

♂ The clypeus and face up to the ocelli is clear yellowish, the rest of vertex and occiput black, but there is a pale line back of the eyes; the antennae are deep black, except the two basal joints which are clear yellow; a yellow band on pronotum; a yellow spot on the posterior part of mesonotum, and yellow above on the scutellum and post-

scutellum, also the tegulae; otherwise the thorax and abdomen are black; the legs are yellowish, except the coxae and basal half of the femora, the extreme tips of hind tarsal joints dark. Wings amber yellow; fore wings with a large brown spot on apex, occupying fully half of the marginal and nearly all of the third submarginal cell; hind wings broadly infusate at tip. The clypeus is broad, broadly and deeply excavate on front margin; the posterior ocelli are a little nearer to each other than to the eyes; the antennae are long and slender, the third joint plainly longer than the fourth, but not equal to vertex width; pronotum almost angulate behind; propodeum an even curve, very distinctly transversely striate; the abdomen is slender, hardly depressed; the legs are slender, with very few spines, the hind tibia with two rows of very short spines above, the inner row of very few spines, and there are some shorter spines below; long spur of hind tibia almost two-fifths of the basitarsus. Fore wings with marginal cell fusiform, pointed at tip; second submarginal nearly twice as long as high, the third submarginal a little larger, scarcely longer, narrowed one-third above; first recurrent ends at apical fourth of second submarginal, second recurrent sinuous, and ends at first third of the third submarginal; in hind wings the anal is interstitial with the cubital fork; the body is hairy, mostly noticeable on propodeum and basal segment. Length 13 mm., fore wing 12 mm.

Monodontonyx (Dinosalius) flavipennis Smith.

Two from Puerto Princesa, Palawan (one Oct., McGregor). To the color description of Smith may be added that the clypeus is elevated at a considerable angle, its lower margin with three small teeth, one in middle and one at each lateral angle; a distinct line from antennae to anterior ocellus; ocelli in a broad triangle, the posteriors nearer to each other than to the eyes; second plus third joints of antennae fully equal to vertex width; pronotum rather deeply arcuate behind; propodeum with a hump-like projection each side near the spiracle, surface coarsely transversely wrinkled, hairy above; basal abdominal segment hairy above, as well as several other segments toward tip, and also on venter; hind tibia above with a row of short teeth each tipped with a spine, and an inner and an outer row of spines and many on the outer side; long spur of hind tibia a little more than one-third of basitarsus. Fore wings with marginal cell long, fusiform, pointed at each end; second submarginal cell more than twice as long as broad, base very oblique, receiving the first recurrent vein some distance before tip; the third submarginal cell much larger.

but little longer than the second, fully one-third narrowed above, receiving the second recurrent vein (bent near middle) a little beyond basal third; in hind wings the anal ends a little before the cubital fork. The male has the face pale, with a large black spot on front and vertex; second and third basal joints of antennae pale, rest black; a yellowish band across end of the pronotum, a spot on mesonotum behind, and on both scutelli. The clypeus is broadly excavate below, almost as much as in *M. javanus*.

Monodontonyx (Dinosalius) gratiosus sp. nov.

♀ Black; with black pubescence on head and thorax, a very faint pale spot at each inner orbit; antennae black, legs black on coxae and femora (except extreme tip), and the tibiae and tarsi yellowish, claws and apex of last tarsal joint black; wings uniformly yellowish, a very narrow dark apical margin. Head, pronotum, scutelli, propodeum, pleura, basal segment of abdomen, apex and venter with long black hair; mesonotum with only short hair and a few bristles; coxae hairy. Clypeus faintly bi-emarginate below; ocelli subequal, no hump, the posteriors not twice as near to each other as to eyes; third joint of antennae about one-third longer than fourth, second plus third more than equal vertex width; scutellum rounded; pronotum nearly angulate behind; propodeum evenly arched, with a median line, and strongly carinate all over; the metapleurae striate; abdomen very convex, rather broad; legs with fairly strong spines on tibiae and tarsi; hind tibia above with an inner row of small teeth with spines, an outer row of spines, and within the inner row is a row of short spines or bristles; long spur of hind tibia more than one-third of basitarsus. Wings fairly broad; radial vein arising toward tip of the stigma; marginal cell fairly long, pointed; third submarginal scarcely twice as long as broad, narrowed one-third above, a little longer than the second; first recurrent ends at apical fifth of second submarginal, second recurrent bowed outward and ends somewhat before the middle of third submarginal cell; in hind wing the anal ends scarcely before cubital fork. Length 19 to 24 mm., fore wing 18 to 23 mm.

From Surigao, Davao, Dapitan, Kolambugan, all in Mindanao; also Island Samar, Island of Biliran, and Cuernos Mts., Negros.

♂ There is a long series of specimens which, I think, must be the males of this *gratiosus*; if not they represent a new species of which there is no female in the collection. The clypeus is yellow, usually with a black median spot, the sides of face are yellow, reaching well up on orbits, the vertex is black and reaching triangularly for-

ward to the antennae; antennae black; pronotum with a yellowish band behind, a spot on the mesonotum behind and the scutelli marked with yellow; legs yellowish, but the coxae and basal part of femora are black. Wings yellowish, but fumose toward tip. Clypeus truncate below; anterior ocellus larger than others, posteriors much nearer to each other than to eyes; antennae moderately long and slender, scarcely crenulate, third joint plus second about equal vertex width; head, pronotum, coxae, pleura, scutelli, propodeum, and basal segment of abdomen with long, yellowish brown hair, several segments near tip of abdomen and the venter also hairy. Pronotum arcuate behind; scutelli somewhat crested; propodeum with a median groove, rugose, but the wrinkles are rather irregular and not very strong. Hind tibia above with two rows of small spines; long spur of hind tibia about two-fifths of basitarsus; venation of wings very similar to that of female. Length 12 to 16 mm.

Specimens from Kolambugan, Dapitan, Iligan, Butuan, Surigao, and Davao, all in Mindanao; Cuernos Mts., Negros; Island of Samar; Island of Biliran; North West Panay; and Mt. Makeling, Luzon; the latter without a spot on the clypeus.

MACROMERINAE.

Synopsis of tribes

1. Hind tibiae with a row of distinct teeth, and always distinct spines; legs not modified in the male; mesopleura not tuberculate below
Priocnemini
Hind tibiae without distinct teeth, the spines very weak or absent, when present, those above are usually in one or more rows. 2
2. Marginal cell of forewings five times (or more) as long as broad; base of second submarginal cell very oblique, the cell three or four times as long as broad, and the first recurrent ending near the tip of cell; legs with some fine erect hairs; clypeus very hairy, hind femora of male enlarged or elongate. *Macromerini*
Marginal cell shorter; base of second submarginal not as oblique, the cell never three times as long as broad, the first recurrent ends near middle of cell; legs without fine erect hairs; clypeus not especially hairy. *Pseudagenini*

MACROMERINI.

Table of genera.

1. Mesopleura not tuberculate below; mid coxae of male enlarged, hind femora elongate, not crenulate below. *Paragenia*
Mesopleura with a distinct cone or tubercle below; femora of male enlarged. 2

2. Hind tibiae without long erect hairs, usually the minute spines distinct.....*Macromerella*
 Hind tibiae with long erect hairs; no distinct spines, the anal cell in hind wing deeply rounded at tip; marginal cell in fore wing blunt at tip.....*Macromeris*

MACROMERIS

Macromeris splendida Lepel.

One specimen from Calian, Davao Prov., Mindanao, 22 June (Clagg).

Macromeris violacea Lepel.

Many specimens from several islands, Luzon, Biliran, Sibuyan, Samar, Negros, and Mindanao, also Sandakan, Borneo. It is most abundant on Mindanao. Widely spread in the Malay region, both continental and insular.

Macromeris iridipennis Smith.

Less common than *M. violacea* of which it is probably but a form or variety; from Luzon, Samar, and Mindanao; also Borneo.

MACROMERELLA gen. nov.

Type *M. aureopilosa* Cam. = *honesta* Smith. Also includes *palawanensis*, and probably *testacea* Bingh. These are so distinct in appearance and lack the fine long hairs on the legs that are so characteristic of true *Macromeris* that I think they should form a separate genus.

Macromerella honesta Smith.

Several from Samar and Cuernos Mts., Negros.

Macromerella palawanensis Lucas

Two from Dapitan and Surigao, Mindanao.

PARAGENIA.

Paragenia argentifrons Smith.

From Mt. Makeling, Los Banos, Mt. Banahao, Luzon, N. W. Panay, and Sandakan, Borneo. Widely distributed in the Malay region and India.

PRIOCNEMINI.

Includes but the one genus, *Priocnemis*, which has several subgenera.

PRIOCNEMIS.

- | | |
|---|-----------------------|
| 1. Thorax reddish; wings with two black bands..... | 2 |
| Thorax black..... | 3 |
| 2. Legs black..... | <i>niobe</i> |
| Legs yellowish..... | North Bornean species |
| 3. Forewings clear, with distinct black bands..... | 5 |
| Forewings without definite black bands, or more or less infusate in stigmal area..... | 4 |
| 4. Prothorax with two large white spots each side, scutellum white; clypeus very plainly tridentate..... | <i>harpalyce</i> |
| Prothorax unspotted, clypeus only indistinctly tridentate; body more or less bluish..... | <i>graphicus</i> |
| 5. Third submarginal scarcely longer than broad, much more than its length from wing tip..... | <i>ariel</i> |
| Third submarginal plainly longer than broad..... | 6 |
| 6. Smaller; third joint not equal vertex width; longer spur of hind tibia about one-half of basitarsus..... | <i>thione</i> |
| Larger; third joint of antennae about equal to vertex width; long spur of hind tibia not nearly one-half of basitarsus..... | <i>astarte</i> |

P. thione, *P. niobe*, and *P. astarte* can be placed in a new subgenus, *Clistoderes*. They differ from others in having a furrow on each side of the propodeum from the spiracle back to end; they have a very large third submarginal cell, hardly its length from wing tip; the second submarginal is very oblique; the clypeus is short, and does not reach under the eyes. *P. astarte* is the type.

In America *P. wheeleri* from Panama has a less distinct furrow each side, but the clypeus is very different.

P. ariel is a *Calicurgus*, the basal and transverse nervures almost or quite interstitial.

P. harpalyce and *P. graphicus* go in *Priocnemella*, having the lateral angles of the clypeus well under the eyes, about at the middle; on the hind tibiae there is no inner row of spines.

Priocnemis graphicus Smith.

Described from the Philippines. Specimens are from Mt. Banahao, Los Banos, Mt. Makeling, Luzon; Island of Sibuyan; Island of Basilan; Butuan, Surigao, and Mt. Apo, Mainit and Sibulan Rivers, 2000 to 6000 ft., 9 Sept., 8 Oct. (Clagg) in Mindanao. Most specimens are, at least, partly bluish, but some are almost wholly black, sometimes hind femora partly red. There is much silvery pubescence on clypeus, lower face, parts of pronotum, lower mesopleura, end of

propodeum, especially the coxae, the legs rarely show any blue, and the tarsi usually brown; wings clear but always a mark across second intercubitals and usually covering the marginal cell or making a large cloud; sometimes a small mark on basal vein; erect white hair on front, pronotum, front coxae, propodeum, and pleura. Clypeus large, its lateral angles extending well under the eyes; its lower margin truncate, with usually a faint indication of three small rounded teeth, one in the middle, and one at each end of the truncature; face mostly concave; ocelli subequal, anterior hardly a diameter from the posterior, the latter very much nearer to each other than to the eyes; antennae slender, third joint much longer than fourth, second and third joints equal to vertex width; pronotum angulate in middle behind; propodeum evenly rounded, with a median line, no striae, but behind punctate; metanotum back of postscutellum very broad, not striated. Abdomen hairy at tip and venter; mid tibiae with two rows of spines above and one on outer side; hind tibiae with an inner row of teeth tipped by spines, an outer row of spines almost from teeth, and a row on outer side. Fore wings with marginal cell almost one-half its length from wing tip; second submarginal about three times as long as broad, receiving the first recurrent beyond the middle; third submarginal longer and much larger than the second, narrowed about one-fourth above, receiving the second recurrent, barely curved, near basal fourth; in hind wings anal interstitial with cubital fork.

What I suppose is the male is bluish in color of body, the mandibles mostly white, the clypeus has a white spot each side (variable in size); the wings are clear except for a shade crossing the end of the second submarginal cell, the third submarginal is suddenly wider below as in the female; antennae and tarsi more or less brownish; the spurs are pale, the hind femora are sometimes pale. The clypeus is truncate below, the mid and hind tibiae have a row of slender spines above, and other spines on sides; antennae long and slender. Length 9 mm.

Priocnemis harpalyce sp. nov.

♀ Black, with a dense silvery pile on clypeus, lower face, coxae, lower mesopleura, apex of propodeum, and a little less distinctly on abdomen and the rest of legs. Pronotum with two large white spots on each side, one above, and other on lower front corner; scutellum white; palpi very pale, and spurs almost white; wings clear, unmarked.

Clypeus broad, lateral angles well under the eyes, front margin truncate, with three large teeth, one in middle and one at each lateral

corner; face but little narrowed above; line from antennae goes only one-half way up; ocelli small, equal, close together, posteriors twice as near to each other as to eyes; antennae slender, third joint very long, much longer than fourth, and of itself equal to vertex width, pronotum behind almost angularly emarginate; propodeum sloping, scarcely arched, hairy above, punctured, mostly behind, not striate. Abdomen slender, with a long pedicel, tip and venter with white hair; mid tibiae with rather long spines, two rows above; hind tibiae with a row of teeth above, tipped by spines, an outer row of spines, and some on outer side, no inner row; long spur of hind tibia fully one-half of basitarsus. Fore wings with marginal cell not one-half its length from wing-tip; second submarginal cell about twice as long as broad, base curved, receiving the first recurrent vein much beyond the middle; third submarginal much longer than the second, and wider behind, outer end bent back so upper side is only one-half of lower, its outer end not far from wing margin, receiving the second recurrent (slightly sinuous) near the basal third; third abscissa of radius a little longer than the second, about equal to the fourth; in hind wings the anal is interstitial with the cubital fork; in fore wings the transverse nervure much beyond the basal.

Length 13.5 mm.; fore wing 12.5 mm.

From Sandakan, Borneo.

Priocnemis (Clistoderes) claggi sp. nov.

♀ Black; wings hyaline; forewings with a broad band over marginal, second and third submarginal and second discoidal cells; hardly a trace of a band over the basal vein. Clypeus more than twice as broad as long, truncate in front; face hardly narrowed above, line from antennae to anterior ocellus; ocelli small, subequal, in equilateral triangle, the posteriors plainly more than twice as far from the eyes as from each other; third joint of antennae plainly longer than fourth, second plus third joints about equal to vertex width; pronotum deeply angulate behind; propodeum elongate, with a distinct broad furrow each side from the spiracle back to the hind border, surface above finely striate, most noticeable behind, not hairy above, but behind white pubescent; metanotum back of postscutellum short, hardly striate in middle, not on sides; pleura with white pubescence. Abdomen slender, fusiform, polished, with white hair toward tip and on venter; legs slender, hind tibiae with row of small teeth above and a few short, fine spines among them, long spur of hind tibia almost

two-fifths of basitarsus. In fore wing the marginal cell is two-thirds its length from wing tip, second submarginal not as long as high, very oblique, and receiving the first recurrent vein at the middle; third submarginal much longer below, but narrowed nearly one-half above, receiving the second recurrent (evenly curved) before end of the basal fourth; transverse nervure plainly beyond the basal vein; in hind wings the anal ends much before the cubital fork.

Length 7 mm.; fore wing 7 mm.

From Hights Place, 8000 ft., Mt. Panay, Benquet, Luzon, 1 to 8 Oct. (Clagg and Rivera).

Differs from *P. astarte* in proportionally wider vertex, in ocelli in equilateral triangle, and in lack of band over basal vein. The antennae are much longer than in *P. thione*.

Priocnemis thione sp. nov.

♀ Black, antennae, palpi, and legs brown to yellow brown; fore wings clear, with two dark bands, one over basal and other, much broader, back of stigma and marginal cell; very little white pubescence. Clypeus truncate across middle below; face but little narrowed above, line from antennae up very indistinct; ocelli equal, close together, the posteriors nearly twice as far from eyes as from each other; antennae rather short and thick; third joint a little longer than the fourth, second and third not equal vertex width; pronotum short, much rounded in front, deeply arcuate behind; propodeum at first nearly level, then sloping behind, densely, finely, transversely carinate, each side with a furrow back from the spiracle, no hair above. Abdomen not very large, hairy at tip and on venter; mid tibiae with short spines, some in rows, hind tibiae with a row of teeth, each tipped by a spine, an inner row of spines, and some on outer side; long spur of hind tibia about one-half of basitarsus. Fore wings with marginal cell one-half its length from wing-tip; second submarginal very oblique, broader than long, receiving the first recurrent vein before the middle; third submarginal more than twice as long as second, and much wider behind, end vein bent in middle, about length of cell from wing-tip, receiving the second recurrent (much curved) before end of basal third; third abscissa of radius twice as long as second, which is plainly shorter than fourth; in hind wings anal ends long before the cubital fork.

Length 6 mm.; fore wings 5.5 mm.

From Mt. Makeling, and Los Banos in Luzon; and Sandakan, Borneo.

Priocnemis niobe sp. nov.

♀ Head and abdomen black; thorax and front (or all) coxae reddish; legs and antennae black; fore wing faintly yellowish, with two broad dark bands across wing, one over basal and transverse, the other, broader, back of stigma and marginal cell, the space between hardly wider than the first band. Clypeus shining, truncate below; face not much narrowed above; line from antennae reaches only one-half way up; ocelli equal, posteriors fully twice as close to each other as to eyes; antennae slender, third joint much longer than the fourth, second plus third nearly equal to vertex width; pronotum rather deeply arcuate behind; propodeum sloping, arched, no median line, but a distinct furrow on each side from the spiracle back to the end; dorsal surface very minutely transversely striate, no hair above. Abdomen fusiform, convex, hairy at tip and venter; mid tibiae with very short spines above; hind tibiae with low, but distinct teeth tipped with spines, and an inner row of spines, other spines on outer side; long spur of hind tibia nearly or quite one-half of basitarsus. Fore wings with marginal cell not one-half its length from wing tip; second submarginal oblique, but little longer than broad, receiving the first recurrent quite a bit before middle; third submarginal very much longer than second, scarcely its length from wing-tip, outer side sinuous, receiving the second recurrent (much curved) before end of basal third; third abscissa of radius much longer than the second and a little longer than the fourth; in hind wing the anal ends much before cubital fork; in fore wings the transverse nervure is one-half its length beyond the basal.

Length 5.5 to 9 mm.; fore wings 5 to 8 mm.

From Mt. Makeling, Luzon; Imugin, N. Viscaya; and Sibulan River, 2000 ft., Mt. Apo, Mindanao, 8 Oct. (Clagg).

Priocnemis astarte sp. nov.

♀ Black, with some silvery pile on body, fairly strong on lower face; wings clear, with two dark bands, one over basal vein, other, very much broader, back of stigma. Clypeus broad, truncate below; face not much narrowed above; line from antennae reaching only one-half way up; ocelli equal, posteriors about twice as near each other as to eyes; third joint of antennae much longer than fourth, second plus third fully equal to vertex width; pronotum short, much rounded in front, angularly emarginate behind; propodeum sloping, transversely wrinkled, faint on the basal part, each side is a broad furrow

from the spiracle back to end. Abdomen rather short, convex, tip and venter hairy; mid tibiae with rows of fairly long spines above, hind tibiae with a row of low teeth, tipped by spines, an inner row of spines, and some on the outer side; long spur of hind tibia hardly two-fifths of basitarsus. Fore wings with marginal cell about one-half its length from wing-tip; second submarginal cell oblique, base much curved, no longer than broad, and receiving the first recurrent near middle; third submarginal cell very much longer than second, hardly more than length from wing-tip, outer side very much curved, receiving the second recurrent vein (much curved above) at basal fifth; third abscissa of radius very much longer than the second and subequal to fourth; in hind wings the anal ends much before the cubital fork; in fore wings the transverse nervure is fully one-half its length beyond the basal.

Length 8 to 9 mm.; fore wing 7.5 to 8.5 mm.

From Mt. Makeling, Baguio Benguet, Luzon; and Zamboanga, Mindanao.

Priocnemis ariel sp. nov.

♀ Black, body mostly clothed with a dense sericeous pile, even on the abdomen, coxae, and femora somewhat sericeous; narrow apical margin of segments pale; wings clear with two dark bands, one over basal and transverse, the other, broader, back from marginal cell, but usually not across the wing. Clypeus truncate below, the margin shining, face much narrowed above, a line from antennae to anterior ocellus; ocelli equal, posteriors very much closer to eyes than to each other; third joint of antennae longer than fourth, and of itself equal to vertex width; pronotum short above, only slightly angularly cut out behind; propodeum short, evenly rounded, densely covered with the silvery appressed hair, some erect hair on sides; abdomen short and broad, hairy at tip and on venter; mid tibia quite densely spined above, hind tibia above with a row of teeth formed of two converging ridges, and tipped with spines, a row of spines on inner side of the teeth; long spur of the hind tibia one-half of basitarsus. Fore wings with marginal cell hardly one-half its length from wing-tip; second submarginal oblique, but little longer than broad, receiving the first recurrent just beyond middle; third submarginal a little longer than second below, narrowed fully two-thirds above, receiving the second recurrent vein (much curved) before the middle; third abscissa of radius much shorter than the second, which in turn is much shorter than the fourth; in fore wings the transverse nervure is only just

beyond the basal (almost like *Calicurgus*); in hind wings the anal ends before the cubital fork.

Length 7 to 9.5 mm.; fore wings 7 to 9.5 mm.

From Mt. Makeling, Mt. Banahao, and Baguio Benguet in Luzon; and Imugin, N. Viscaya.

PSEUDAGENINI.

This group is found throughout the world and contains many hundred species. There is a great variety of form particularly in the tropical species. I have therefore thought it useful to divide it into a number of genera, most of which are new; further study may show that some are but subgenera; however, I think that it is more likely that the genera will be greatly increased, rather than lessened. Especially distinct I think are *Dinagenia* and *Meragenia*, both readily recognizable in both sexes; *Minagenia* is also easily known in both sexes, and *Tumagenia*, when the male is known, will probably also agree with the female. *Conagenia* and *Phanagenia*, as far as I know now, are separable only in female from the old *Pseudagenia*.

PSEUDAGENINI.

Synopsis of genera.

1. The last three joints of maxillary palpi not especially elongate, but somewhat thickened at end; pronotum with the groove on side turned up under the upper lobe, not downward toward lower corner; first abdominal segment fully equal to the second, which is not enlarged *Dinagenia*
Last three joints of maxillary palpi very elongate, slender, not thickened near their ends. 2
2. Front with two large, elongate tubercles above the antennae; body very slender. *Tumagenia*
No such elevations on the front. 3
3. Clypeus below with a distinct nose-like median projection (not simply acute) *Conagenia*
Clypeus without such definite process. 4
4. A broad basket of curved bristles beneath head, over the mouth parts; median vein of fore wing usually reaches margin. *Deuterationia*
No such broad basket of bristles, only a few (six) in middle, usually hidden or nearly united. 5
5. Pronotum as long as mesonotum, transverse behind, and its anterior lateral angles somewhat produced so that the pronotum is transverse in front; pronotum and rest of thorax granulate or pitted; clypeus not pointed in middle below; antennae short and thick. *Meragenia*
Pronotum shorter, not granulate, rounded on sides in front. 6

6. Mesonotum behind longitudinally striate; first recurrent ends at tip of second submarginal cell. *Lophagenia*
Mesonotum not longitudinally striate. 7
7. Lower mesopleura projecting in a cone-shaped manner. *Calagenia*
Lower mesopleura rounded. 8
8. Last tarsal joint with a few spines or bristles beneath. *Phanagenia*
Last tarsal joint smooth beneath. 9
9. Median vein reaches the wing margin, very fine, but distinct; clypeus almost truncate. *Minagenia*
Median vein stops before margin; clypeus rounded or in point below. *Pseudagenia*

PSEUDAGENIA.

Females.

1. Clypeus more or less white or yellowish. 2
Clypeus black or brown. 10
2. Mesopleura more or less reddish, or with pale spot; legs mostly yellowish. 3
Mesopleura black. 6
3. Pronotum wholly reddish, antennae pale on base. *pardalice*
Pronotum dark, with posterior border and down along side to front yellow or reddish. 4
4. Abdomen wholly reddish; basal part of antennae dark; propodeum mostly reddish. *doralice*
Abdomen black, with yellow bands. 5
5. Propodeum yellow behind; basal joint of antennae wholly pale, a spot on upper metapleura as well as on lower mesopleura. *eurydice*
Propodeum not yellow at tip; basal joint of antennae black above; no spot on upper metapleura. *eurydice* var. *nestor*
6. Pronotum yellowish behind; yellow line by orbits; legs partly yellowish; small species. *pictoides*
Pronotum not yellowish behind, at most with silvery pubescence. 7
7. Hind femora reddish; faint yellow mark in lower orbits. *bimaculata*
Hind femora black; no yellowish in orbits. 8
8. Clypeus distinctly not pointed in middle below, but broadly rounded, almost truncate; basal joints of antennae not pale beneath; pale spots on clypeus at lateral corners; body blue black. *ilione*
Clypeus distinctly somewhat pointed in middle below; antennae black for most of length. 9
9. Basal joints of antennae pale beneath; pleura and propodeum not heavily punctate. *rizali*
Basal joints of antennae black beneath; pleura and propodeum heavily punctate. *confraterna*

10. Thorax wholly reddish; wings with dark bands. *ashmeadi*
 Thorax not reddish. 11
11. Fore wings with some definite dark mark, or spot. 12
 Fore wings wholly clear, or at least not black. 18
12. Abdomen with basal part red; forewings almost wholly dark. *hesione*
 Abdomen not red on base. 13
13. Body distinctly bluish. 14
 Body not plainly bluish. 15
14. Clypeus pointed in middle below. *rohweri*
 Clypeus truncate in middle below. *alcidice*
15. Stigmal dark band very narrow, not extending into the third sub-
 marginal cell, nor beyond second discoidal cell; the basal and trans-
 verse nervure practically interstitial. 16
 Stigmal band broader, going into the third submarginal and beyond
 the second discoidal cell. 17
16. Clypeus below in a single median rounded point. *unifasciata*
 Clypeus below in two separated points, and somewhat emarginate
 between them. *nitidiventris*
17. Clypeus distinctly pointed in the middle below; median does not
 quite reach margin. *morota*
 Clypeus gently evenly rounded, almost truncate below; median vein
 reaches to the wing margin. *Minagenia*
18. Hind femora plainly partly reddish. 19
 Hind femora black. 23
19. Third joint of antennae short, plainly not equal to vertex width. 20
 Third joint of antennae long, about equal to vertex width. 22
20. Third joint plainly longer than the fourth front tibiae and mid
 femora black. *persephone*
 Third joint scarcely longer than fourth. 21
21. Front tibia pale, mid femora usually reddish in part; posterior
 ocelli nearer to each other than to eyes. *rufofemorata*
 Front tibia black as well as mid femora; posterior ocelli about as near
 to eyes as to each other. *marcia*
22. Body distinctly blue (or greenish); clypeus distinctly in a rounded
 point below; palpi white; ocellar area not swollen. *blanda*
 Body black; clypeus rounded below; palpi brownish. *tagalensis*
23. Body distinctly bluish in part. 24
 Body black. 28
24. Clypeus distinctly somewhat emarginate in middle below; palpi
 white. *bakeri*
 Clypeus not emarginate below. 25
25. Basal joint of antennae pale beneath; third joint of antennae not
 equal vertex width; mandibles white in part. *capella*
 Basal joint of antennae dark beneath; third joint equal to vertex
 width. 26

26. Interocellar area much swollen, clypeus broadly rounded below. *nyemitawa*
Interocellar area not swollen. 27
27. Clypeus strongly pointed below; a faint dark mark below stigma;
third joint of antennae hardly equal vertex width. *rohweri*
Clypeus not strongly pointed; no wing mark; third joint of antennae
fully equal vertex width. *makelingi*
28. Third joint of antennae fully equal to vertex width; face narrow,
orbits subparallel; interocellar area swollen. *innotata*
Third joint of antennae not equal to vertex width. 29
29. First recurrent ends toward tip of the second submarginal cell; front
with much long hair, vertex much broader than clypeus. *macromeroides*
First recurrent vein ends near middle of second submarginal cell;
hair on front much shorter; vertex narrowed from the middle. 30
30. Front legs largely reddish; interocellar area not swollen. *circe*
Front legs black. 31
31. Interocellar area swollen; third antennal joint plainly longer than
fourth. *okawa*
Interocellar area not swollen; third antennal joint scarcely longer
than fourth. *clotho*

Males of Pseudagenia (including *Phanagenia*,
Conagenia, and *Minagenia*).

1. In the fore wings the median vein reaches the outer margin of wing,
very fine, but distinct; clypeus very broad, truncate, small species;
abdomen without distinct pedicel. *Minagenia* (2)
In forewings the median stops short plainly before the margin. 3
2. Antennae moderately slender, pale under basal part. *assimilis*
Antennae very short and thick (like a *Meragenia*), rarely pale under
basal joint. *brevicornis*
3. Femora (at least hind pair) yellowish or reddish. 4
Femora, at least hind pair black. 14
4. Forewings clear, unspotted. 7
Forewings with a dark cloud. 5
5. Antennae black or brown; triangular spot each side on lower face
pale. *No. 5*
Antennae yellowish, lower margin of clypeus and lower orbits narrowly
yellow; tips of wings white. 6
6. Clypeus yellow. *No. 6*
Clypeus black. *Phanagenia chrysosoma*
7. Pronotum mostly yellow above; legs mostly yellow. *No. 2*
Pronotum wholly dark. 8
8. Abdomen with yellowish band across the middle; clypeus black; base
of antennae yellow. *No. 3*
Abdomen without yellow band. 9

9. Front and mid femora largely yellowish; a pale line up each orbit;
basal antennal joint pale beneath; mandibles white *No. 4*
Front and mid femora largely dark 10
10. Vertex and thorax more or less bluish; clypeus and lower part of face
wholly white. *blanda*
Vertex and thorax not bluish; clypeus and lower face not wholly
white. 11
11. Clypeus with two large white spots 12
Clypeus black 13
12. Mandibles mostly white, except base. *bimaculata*
Mandibles wholly black. *tagalensis*
13. Basal segment of abdomen with yellowish band. *rufofemorata*
Basal segment of abdomen not banded. 14
14. Thorax partly red above; black bands on the wings. *Conagenia aegina*
Thorax not reddish above. 15
15. Forewings without dark marks 16
Forewings with dark marks 21
16. Body more or less bluish. 17
Body black, or brown 18
17. Clypeus and lower face white. *makelingi*
Clypeus and lower face mostly black. *capella*
18. Clypeus with two white spots or almost wholly white; spurs dark. 19
Clypeus not marked with pale. 20
19. Basal joint of antennae black beneath. *confraterna*
Basal joint of antennae pale beneath. *rizali*
20. Marginal cell subtriangular, narrowing the second submarginal at
tip. *macromeroides*
Marginal cell elongate, not narrowing the second submarginal. *okawa*
21. Clypeus white each side; lower orbits white 22
Clypeus not white each side. 24
22. Stigmal mark is a narrow band, border of clypeus only white. 23
Stigmal mark is a broader band, clypeus almost wholly white; spurs
white. *morota?*
23. Mandibles with a distinct white spot, side spots on clypeus fairly
large, lower middle margin of clypeus black. *Phanagenia banoensis*
Mandibles without white spot, side marks very narrow, and continued
along entire lower margin. *unifasciata*
24. Clypeus fully twice as broad as long, almost truncate below. 25
Clypeus not twice as broad as long in middle, somewhat rounded
below. 26
25. With large dark spot from stigma outward; large species.
..... *Phanagenia negritos*
With a narrow transverse stigmal band; small species. *nitidiventris*

26. Palpi white, no mark over basal vein, a large stigmal mark, the tip white, lower margin of clypeus, and the lower orbits often pale; the transverse nervure well beyond the basal vein. *No. 1*
 Palpi dark, at least gray. 27
27. Transverse nervure widely separated from the basal vein, no distinct mark over basal, spurs dark. *No. 7*
 Transverse nervure little if any beyond the basal vein, a cloud over basal. 28
28. Spurs (at least inner) snow white, no pale on lower orbits.
 *Conagenia williamsi?*
 Spurs only slightly whitish, some pale in the lower orbits. . . *Conagenia smithi?*

Pseudagenia alcidice sp. nov.

♀ Body metallic bluish, antennae black; legs with femora and tibiae bluish or purplish, tarsi brown; spurs brown. Fore wings clear, with broad black band from beyond stigma across wing, the tip almost clear, hind wings clear. Face and clypeus strongly silvery, some also behind on propodeum and lower mesopleura. Clypeus sloping each side in front, but with a short median truncate border, about one-fourth of width; line from antennae to anterior ocellus; ocelli subequal, posteriors much closer to each other than to eyes; third joint of antennae longer than fourth, second and third about equal vertex width; pronotum angulate behind; propodeum transversely striate, hairy above. Abdomen fusiform, convex, basal segment with short pedicel, hairy near tip; legs with a few very short spines on mid and hind tibiae; long spur of hind tibia not quite one-half of basitarsus. Fore wings with marginal cell about one-half its length from wing-tip; second submarginal cell twice as long as broad, base curved, receiving the first recurrent vein at middle; third submarginal cell scarcely longer below than second, much wider behind, receiving the second recurrent vein (somewhat curved) a little before end of basal third; third abscissa of radius a little longer than the second, which equals the fourth; in hind wings the anal ends before the cubital fork.

Length 8 to 9 mm.; fore wing 7 to 8 mm.

Island of Samar.

Pseudagenia ashmeadi sp. nov.

♀ Head and abdomen black, thorax reddish; antennae black; palpi gray; legs brown to black, front coxae reddish as thorax, rest of front legs somewhat ferruginous; wings clear, with two black bands, one rather narrow, over basal and transverse, the other, much broader, from stigma and marginal cell back across wing. Clypeus

and lower face with some silvery pubescence, and fainter at tip of propodeum. Clypeus very distinctly pointed below in middle, the point reddish; ocelli subequal, the posteriors nearer to each other than to the eyes; a few erect hairs on sides of front; third joint of antennae longer than fourth, second plus third equal vertex width; pronotum angulate behind; propodeum low, sloping, without distinct carinae, and almost without hair above; metanotum back of post-scutellum with distinct striae; abdomen short, basal segment much narrowed at base, some fine hairs toward tip, and on venter; legs slender, some minute spines on mid tibiae above, on hind tibiae scarcely visible; long spur of the hind tibia about one-third of basitarsus. In fore wing the marginal cell is hardly one-half its length from wing-tip; second submarginal not quite twice as long as broad, base curved, receiving the first recurrent vein a little before the middle; third submarginal about as long as second, but narrowed above, receiving the second recurrent (bent near middle) near basal third; third abscissa of radius a little shorter than the second, latter hardly equal to fourth; in hind wings the anal ends much before the cubital fork.

Length 7 mm.; fore wing 6 mm.

From Island of Basilan; a specimen from the island of Panay is a variation with the legs (except tarsi) reddish, and the basal joints of antennae somewhat reddish.

Pseudagenia bakeri sp. nov.

♀ Body metallic blue, with a silvery pubescence, most heavy on clypeus, lower face, lower mesopleura and coxae; erect white hair on vertex, front coxae, pronotum, scutelli, and propodeum, hardly shorter on the pleura; apical half of palpi white; antennae black; legs with femora bluish, the rest brown; wings nearly hyaline, unmarked. The clypeus is moderately long, below with two submedian humps and the space between concave; third joint of antennae fully equal vertex width; ocelli subequal, no prominent hump between them, the posteriors fully as near each other as to the eyes; pronotum deeply arcuate behind; propodeum finely transversely carinate, in certain lights a median line; metanotum behind postscutellum striate. Abdomen with some very short hair on basal segment, longer at tip, short on venter; mid and hind tibiae with minute spines; long spur of hind tibia more than one-half of basitarsus. Fore wings with marginal cell long, much less than one-half its length from wing-tip; second

and third submarginal cells long, second over twice as long as high, receiving the first recurrent near middle; third submarginal hardly as long as second, wider behind, receiving the second recurrent vein just before the end of basal third; third abscissa of radius a little shorter than second, about equal to the fourth; in hind wing the anal ends scarcely before the cubital fork.

Length 11 mm.; fore wing 10.5 mm.

From Island of Samar; Island of Sibuyan; Island of Biliran; Surigao, Mindanao; and N. W. Panay.

It greatly resembles *P. makelingi* Wills., but is readily separated by the emarginate middle of the clypeal border.

Pseudagenia bimaculata Smith

Specimens from Dapitan, Davao, Butuan, Surigao, Kolambugan in Mindanao; Island of Basilan; and Island of Samar.

The clypeus is a rounded wedge below; the face plainly widened in middle, and narrowed at vertex, a line from antennae to anterior ocellus; the ocelli subequal, the posteriors almost as near to eyes as to each other, a groove back of each posterior ocellus; third joint of the antennae much longer than the fourth, and of itself equal to the vertex width; pronotum moderately long, only slightly angularly emarginate behind; propodeum slightly arched, finely transversely carinate, rather densely punctate, hairy above, a median furrow at base; mid and hind tibiae with short, but very distinct spines, above in rows; long spur of hind tibia about one-half basitarsus. Fore wings with long marginal cell less than one-half length from wing tip; second submarginal cell more than twice as long as broad, base oblique, little curved, receiving the first recurrent vein near middle; third submarginal cell longer below than the second, much narrowed above, receiving the second recurrent (slightly curved) at basal third; third abscissa of radius usually a little longer or equal to second, this plainly longer than fourth; in hind wings the anal ends plainly before the cubital fork; in fore wing the transverse nervure is oblique and one-third its length beyond basal. The clypeus is often almost wholly white, only an incomplete dark median line.

The male (as the female) has two large pale spots on the clypeus, and the mandibles are largely white; there is usually a pale line on each lower orbit, the under surface of basal antennal joint is usually marked with pale; the hind femora largely reddish, otherwise the body and legs black; wings clear or almost so, unmarked; venation as

in female; third joint of antennae only a little longer than fourth; clypeus fully twice as broad as long, rounded below; face broad; line from antennae goes up only a short distance; ocelli subequal, posteriors as near to each other as to eyes; long spur of hind tibia two-thirds of basitarsus; venation as in female.

Pseudagenia blanda Guerin.

Many specimens mostly from Sandakan, Borneo; Dapitan, Davao, Butuan, and Surigao in Mindanao; a few from Island of Samar; Island of Basilan; Island of Biliran; and Mt. Makeling, Luzon.

The male is bluish, the hind femora reddish; the labrum, clypeus, lower face, and suprantennal process white; a stripe on under side of basal joint of antennae, and the under sides of the other joints except at ends also white; usually some white on front coxae; the abdominal segments with narrow apical margin pale, and last segment above white.

Specimens also from Singapore and some of these have white on each side of sixth segment and thus agree with Bingham's *Pseudagenia albilabris* which is thus apparently the male of *P. blanda*.

Pseudagenia capella Williams.

Described as *P. caerulea*, but that name being preoccupied, it was changed by Williams (Ent. News XXXI, 84, 1920) to *P. capella*.

Specimens are from Los Banos, Mt. Makeling, Mt. Banahao, Luzon; Surigao, Kolambugan, Butuan, Dapitan, Davao, Zamboanga, in Mindanao; Cuernos Mts., Negros; Island of Basilan; Island of Biliran; Island of Samar; Island of Sibuyan; N. W. Panay.

Basal joints of antennae distinctly pale beneath, mandibles partly white. The spines on mid and hind tibiae are scarcely distinct; the long spur of hind tibia a little more than one-half of basitarsus; fore wings with marginal cell more than one-half its length from wing-tip, second submarginal cell almost or quite twice as long as broad, the base curved and somewhat oblique, receiving the first recurrent at the middle; third submarginal cell somewhat longer below than second, about one-third narrowed above, receiving the second recurrent vein near (or before) basal third; third abscissa of radius a little longer than the second which is little if any longer than fourth; in hind wings the anal ends much before the cubital fork; in fore wings the transverse nervure is a little beyond the basal vein.

The male is slender, bluish, with pale line in each inner orbit, but

generally very similar to the female. There is some variation (as in other Psammocharids) in the depth of the striae on the propodeum; it is quite possible that this is *P. lucilla* Smith.

Pseudagenia circe sp. nov.

♀ Black; front femora (except base) and the front tibiae reddish yellow; tarsi and other legs black; wings clear, unmarked. Clypeus, lower face, pronotum in parts, sides of propodeum, coxae, much of pleura with silvery pubescence. Clypeus almost coming to a rounded point in middle below; face moderately narrow and narrowed above; line from antennae to anterior ocellus; ocelli subequal, the posteriors a little nearer to each other than to eyes; third joint of antennae plainly longer than fourth, second plus third not equal vertex width; pronotum behind slightly but distinctly angularly emarginate; propodeum rounded, hairy above, on basal part distinctly finely transversely striate, less plain behind; mid and hind tibiae practically without spines. In the fore wings the marginal cell more than one-half its length from wing tip, the third and fourth abscissae nearly in line; second submarginal cell nearly one-half longer than broad, base oblique, receiving the first recurrent vein at middle; third submarginal cell very much longer and broader behind than the second, about one-third narrowed above, receiving the second recurrent (slightly bent in middle) at about basal fourth; in hind wings the anal ends plainly before the cubital fork; in fore wings the transverse nervure one-third its length beyond the basal.

Length 8.5 mm.; fore wing 8 mm.

From Mt. Makeling, Luzon and Surigao, Mindanao.

Pseudagenia clotho sp. nov.

♀ Black; mandibles and under side of the basal antennal joint black; wings clear. White pubescence on clypeus, lower face, pronotum, pleura, coxae, and end of propodeum. Clypeus rounded below; face rather broad, but narrowed above, a faint line from antennae to anterior ocellus; ocelli in a moderately broad triangle, the posteriors almost as near to eyes as to each other; third joint of antennae a little longer than fourth, second plus third not nearly equal to vertex width; pronotum behind slightly angularly emarginate; propodeum sloping, hairy above, with an indistinct median line, finely but plainly transversely striate, punctate behind; mid tibiae with distinct, though minute spines, hind tibiae practically without spines; long spur of

hind tibia about one-half of the basitarsus. In fore wings the marginal cell is fully one-half its length from the wing tip; second submarginal cell almost twice as long as broad, base quite oblique, receiving the first recurrent vein near the middle; third submarginal cell long and wider behind than second, narrowed about one-third above, receiving the second recurrent (slightly curved) at basal third, in hind wings the anal is almost interstitial with the cubital fork; in fore wings the transverse nervure is a little beyond the basal vein.

Length 6 to 7 mm.; fore wing 6.5 mm.

Of the size and appearance of a dark *P. capella*, but the black mandible and dark underside of basal antennal joint separates it.

Pseudagenia confraterna sp. nov.

♀ Very similar to *P. rizali*, and may be but a subspecies of that form.

It has a clypeus with two large white spots, sometimes occupying almost the entire clypeus. It differs from *P. rizali* in that the basal joint of the antenna is black beneath, the antennae beyond basal third usually ferrugineous; legs without the pale bands at base of mid and hind tibiae; the abdominal segments scarcely margined with paler; in the hind wing the anal is almost or quite interstitial with the cubital fork; long spur of hind tibia hardly one-half of basitarsus; the pleura and propodeum are much more densely punctate than in *P. rizali*.

Length 8 mm.; fore wing 7.5 mm.

From Mt. Makeling and Los Banos, Luzon; and the Island of Samar.

The male of this is very similar to that of *P. rizali*; the clypeus white, with a median black spot, the under surface of the basal joint of antenna is black as in the females; the front tibiae are pale. The ocelli are rather close together, in a nearly equilateral triangle, posteriors hardly two diameters apart; long spur of hind tibia a little more than one half of basitarsus; propodeum moderately rugose; about one-half of basal segment of abdomen is a petiole.

Pseudagenia doralice sp. nov.

♀ Body yellow, marked with shining black, a median black line on the clypeus; a large black spot on vertex, reaching to each eye and broadly in front down to the tubercles above base of antennae; occiput black, in middle reaching to eye for short distance; pronotum

with a broad black band in front, reaching a short distance on sides; mesonotum almost wholly black, but with a yellow spot; upper part of mesopleura largely black, a broad black stripe each side on upper propodeum, extreme base of first abdominal segment black; antennae black, apical half pale; legs yellow; wings nearly clear or faintly yellowish, unmarked; stigma rather yellowish, as also veins; body with little hair. Clypeus not very long, but coming to a point in middle below; line from antennae to anterior ocellus; ocelli subequal, posteriors about twice as near each other as to eyes; third joint of antennae but little if any longer than fourth or fifth; second plus third almost equal to vertex width; pronotum angulate behind; propodeum low, nearly flat, with median groove, and many fine transverse carinae, above with short hair; abdomen slender, fusiform, with a fairly long pedicel, tip and venter with a little fine white hair; legs with minute spines on mid and hind tibiae, long spur of hind tibia two-thirds of basitarsus. Fore wings with marginal cell about one-half its length from wing-tip; second submarginal twice as long as broad, base curved, receiving the first recurrent vein near middle; third submarginal cell scarcely longer than the second, wider behind, and much narrowed above, receiving the second recurrent vein (scarcely curved) near the basal third; second, third, and fourth abscissa of radius subequal; in hind wings the anal is much before the cubital fork.

Length 10.5 mm.; fore wing 9.5 mm.

From Mt. Banahao, Luzon.

Male marked about as female, body rather more slender, antennae somewhat paler, basal joint below pale; spines on hind tibiae scarcely visible; long spur of hind tibia only about one-half of basitarsus; venation as in female.

Length 9 mm.

From Baguio Benguet, Luzon.

Pseudagenia eurydice sp. nov.

♀ Black, much marked with whitish as follows: clypeus, mandibles, a broad stripe up each orbit half way, posterior border of pronotum, extending down on the hind edge of the side and then forward for a distance; spot on mesonotum behind, on scutelli, large spot each lower side of mesopleura, and another on the side of the metanotum, spot each side behind on propodeum, usually connected, the coxae almost wholly; more than apical half of first segment of abdomen, the apical third of second, third, and fourth segment, and part of last

dorsal segment. Legs yellowish, the tarsi, hind femora, and tips of tibiae darker, spurs pale; antennae brown, paler toward tips, and the basal joints yellow. Vertex and propodeum with short hair. Clypeus not very long, but coming to a point below, line from antennae to anterior ocellus; ocelli moderately large, subequal, posteriors a little closer to each other than to eyes; third joint of antennae longer than fourth, second plus third fully equal to vertex width; pronotum almost angulate behind; propodeum low, slightly arched, with fine transverse carinae on basal part, fainter near tip; abdomen with moderate pedicel, rather broadly fusiform, hairy near tip, but very faint on venter. Legs with extremely indistinct spines on mid and hind tibiae; long spur of hind tibia fully one-half of basitarsus. In fore wing the marginal cell is about two-thirds its length from wing-tip; second submarginal cell not twice as long as broad, base curved, receiving the first recurrent vein a little beyond the middle; third submarginal cell longer than the second, and much wider behind, receiving the second recurrent (slightly curved) at basal third; third abscissa of radius much longer than the second, latter about equal to fourth; in hind wings the anal ends much before the cubital fork.

Length 8 mm.; fore wing 7.5 mm.

From Mt. Makeling, Los Banos, Luzon.

Pseudagenia curydice var. *nestor* nov. var.

Similar in markings to typical form but differs as follows: The basal joints of the antennae are black above, the large black spot on front is somewhat widened in middle, no spot on postscutellum, no large spot on side of metanotum, nor any at the tip of propodeum; the propodeum has a sericeous pubescence and the transverse striae are very indistinct; venation the same.

From Surigao, Mindanao.

Pseudagenia hesione sp. nov.

♀ Black, clypeus and lower face silvery white; basal half of abdomen reddish; legs black, hind femora reddish; antennae black; fore wings almost wholly black, except the extreme base, iridescent; hind wings slightly infuscate. Body slender; clypeus short and broad, truncate below; line from antennae going only a short distance; ocelli fairly large, subequal, close together, posteriors but little more than diameter apart, more than twice as far from the eyes; antennae short and thick, third joint very much longer than fourth, latter not

equal to first, second plus third not equal to vertex width; pronotum moderately long, arcuate behind; propodeum evenly arched, short hair above, densely rugoso-punctate, in middle somewhat transversely wrinkled; pleura short-haired; abdomen fusiform, short petiolate, with very short hair near tip and on the venter; mid and hind tibiae with a few very fine spines; long spur of hind tibia a little more than one-half the basitarsus. Fore wings with marginal cell nearly out to tip, not one-fifth of its length from wing-tip; second submarginal twice as long as broad, base slightly curved, receiving the first recurrent vein at middle; third submarginal cell longer and much wider behind than second, but little narrowed above, receiving the second recurrent vein (much curved) scarcely beyond basal fourth; third abscissa of radius considerably longer than second, which is much longer than the fourth, first but little shorter than fourth; in hind wings the anal ends much before the cubital fork.

Length 7 mm.; fore wing 6.5 mm.

From Sandakan, Borneo. One female. Probably related to *P. reticulata* Cam. from Borneo, but that is much larger, the third abscissa of radius shorter than the second, etc.

Pseudagenia ilione sp. nov.

♀ Body bluish black, with much silvery pubescence, dense on face, clypeus, coxae, parts of pleura and pronotum; a white spot at each outer corner of clypeus, covered with silvery pile; antennae pale brownish, basal joint darker; palpi pale; legs mostly brown, somewhat purplish on femora; wings clear. Erect white hair on face, pronotum, front coxae, propodeum and pleura, much longer and dense hair on occiput each side. Clypeus moderately large, but not long, practically truncate below; ocelli small, subequal, posteriors about twice as near each other as to eyes; third joint of antennae scarcely longer than fourth, second plus third not equal to vertex width; pronotum angulate behind; propodeum sloping, not arched, with median line, striae too faint to be noticed; metanotum back of postscutellum broader than usual, not striate. Abdomen not petiolate, basal segment rather flattened and broad at base, hairy above, other hairs at tip and short hair on venter; mid and hind tibiae with a few short spines above in rows; long spur of hind tibia about three-fifths of basitarsus. Fore wings with marginal cell hardly one-half its length from wing-tip; second submarginal cell almost twice as long as broad, base curved, receiving the first recurrent near middle;

third submarginal plainly longer and larger than second, receiving the second recurrent vein (slightly curved) near the basal third; third abscissa of radius a little longer than the second, which is about equal to the fourth; in hind wings the anal is interstitial with the cubital fork.

Length 7.5 mm.; fore wings 6.8 mm.

From Mt. Makeling, Luzon.

Pseudogenia innotata sp. nov.

♀ Black, with a whitish pubescence on lower face, clypeus, coxae, parts of pronotum, mesopleura, and apical part of propodeum, and less distinctly on the abdomen; palpi gray; wings clear, unmarked. Clypeus rounded below, almost into a point; a line from antennae to anterior ocellus; ocelli subequal, situated at the base of an inter-ocellar hump, the posteriors about as near to eyes as to each other, third joint of antennae long and slender, much longer than the fourth, and of itself fully equal to vertex width; front with erect, short, white hair, longer on the vertex; pronotum slightly rounded behind; propodeum evenly arched, with a median furrow, faintly, transversely wrinkled, but also heavily punctured, above with long white hair, pleura also white haired; abdomen with a short pedicel, very convex, basal segment short haired above, tip and venter with longer hair; mid and hind tibiae with distinct, though short spines, above mostly in rows; long spur of hind tibia more than half of the basitarsus. Fore wings with marginal cell fully one-half its length from wing-tip; second submarginal cell about twice as long as broad, base straight and oblique, receiving the first recurrent vein plainly beyond middle; third submarginal cell a little longer than the second, but not much wider behind, considerably narrowed above, receiving the second recurrent vein (very slightly curved) near basal third; third abscissa of radius plainly longer than second, which is but little longer than the fourth; in hind wings the anal is interstitial with the cubital fork.

Length 12.5 mm.; fore wings 11 mm.

From Mt. Makeling, Luzon; and Cuernos Mts., Negros.

Pseudogenia macromeroides Williams.

From Cuernos Mts., Negros; and Island of Samar.

■ Interocellar area somewhat swollen, posterior ocelli nearer to each other than to eyes; second plus third antennal joints not equal to

vertex width. The marginal cell is triangular, broadest at the end of second submarginal cell which it narrows, it is more than one-half its length from the wing tip; second submarginal cell one-half longer than broad, base curved, tip short, receiving the first recurrent vein beyond the middle, third submarginal cell much longer and wider behind than second, about one-third narrowed above, receiving the second recurrent vein (slightly outcurved) a little beyond basal third; third abscissa of radius longer than the second and this longer than fourth; in hind wings the anal vein ends at or just beyond cubital fork; in fore wings the transverse nervure is just a little beyond the basal. The palpi are brown. This is probably the *Agenia facilis* of Smith from Macassar. The peculiar shape of the marginal cell is noted by Smith, and otherwise his description fits, but since there are several species that have such a cell (*alcidice*, *nitidiventris*) it may well be that there is still another in southern Celebes.

Pseudagenia makelingi Williams.

Described from Mt. Makeling; specimens from N. W. Panay; Island of Sibuyan; Kolambugan, Mindanao; Cuernos Mts., Negros.

Interocellar area not swollen, the ocelli subequal; posteriors closer to each other than to the eyes; third joint of antennae equal to the vertex width; mid and hind tibiae practically without spines; long spur of hind tibia about two-fifths of basitarsus. Fore wings with marginal cell long, only about one-third its length from the wing-tip; second submarginal twice as long as broad, base oblique, receiving the first recurrent near middle; third but little longer below than the second; about one-fourth narrowed above, receiving the second recurrent (bent in middle) at about basal fifth; third abscissa of radius scarcely longer than the second and both a little longer than fourth; in fore wings the transverse nervure is plainly (but not greatly) beyond the basal.

Pseudagenia marcia sp. nov.

♀ This is a species of the size and general appearance of *P. rufofemorata*, the hind femora only red, the mid femora and front tibiae black; wings often somewhat tinted, but without marks; silvery pubescence much as in *P. rufofemorata*. The clypeus is rounded below, hardly in a rounded median point; a line from antennae to anterior ocellus; the ocelli in a rather broader triangle than in *P. rufofemorata*, so that the posteriors are about as near to eyes as to each other; the

antennae have the third joint a trifle longer than fourth, second plus third not equal to vertex width; pronotum scarcely emarginate behind; propodeum rounded, hairy above, with a median line, surface punctate; mid and hind tibiae without spines; long spur of hind tibia more than one-half basitarsus; venation much as in *P. rufofemorata*, but the third submarginal cell is not as broad behind.

Length 6 to 7 mm.

From Dapitan, Kolambugan, Butuan, Iligan, and Davao in Mindanao; and Sandakan, Borneo. In some specimens there is a faint greenish tinge on the head.

Pseudagenia morota sp. nov.

♀ Black, with some silvery pubescence, most distinct on clypeus and lower mesopleura; palpi gray; legs and antennae often somewhat brownish. Fore wings clear, with two distinct black bands one over the basal and transverse, nearly across wing, the other, broader, behind marginal cell back almost or quite across wing; the middle point of the clypeal border is usually ferrugineous, as also the mandibles; sometimes the front tibiae are pale. Head and thorax densely minutely punctate, with few erect hairs on head and thorax, almost absent from pleura and propodeum. Clypeus pointed in middle below; a short line above antennae up, but soon ending; anterior ocellus scarcely larger than the others, posteriors much nearer to each other than to the eyes; third joint of antennae but little longer than the fourth, second plus third about equal vertex width; pronotum rather deeply emarginate behind, propodeum granulate in a transverse way, no median groove; the entire thorax rather depressed, more like *Meragenia*. Abdomen with hair at tip and on venter; legs with almost no spines on hind tibiae, those on mid tibiae project slightly above their pits; long spur of hind tibia one-third (or more) of basitarsus. Fore wings with marginal cell more than one-half its length from the wing-tip, second submarginal hardly twice as long as broad, its base curved, receiving the first recurrent vein at about middle; third submarginal cell but little longer than the second, somewhat wider behind, receiving the second recurrent (plainly curved) at basal fifth or sixth; third absicra of radius rather shorter than the second, and about equal to the fourth; in hind wing the anal vein ends much before the cubital fork.

Length 6 to 7.5 mm.; fore wing 5.5 to 6.5 mm.

From Los Banos and Mt. Makeling, Luzon; Iligan, Dapitan, and

Surigao, Mindanao; Puerto Princesa, Palawan; Island of Sibuyan; Island of Basilan; Malinao, Tayabas; Tanglecolan, Bukidnon; and Sandakan, Borneo.

What is probably the male of this species is quite abundant on Luzon (as is the female) with a few specimens from the southern islands. It is more slender, black, the clypeus white, with a median dark spot, not reaching anterior margin, the white extends, rather broadly, half way up each orbit; the under side of the basal antennal joint pale, the spurs pale, often nearly white; the wings have the broad stigmal band and the tip clouded, sometimes the two unite; last segment of abdomen above white. The clypeus is a little rounded below, almost truncate; the posterior ocelli much closer to each other than to the eyes, the basal segment of abdomen practically all petiole; long spur of hind tibia more than half to nearly two-thirds of basitarsus; venation as in female.

Pseudagenia nitidiventris Smith.

Specimens from Davao, Dapitan, Zamboanga, Mindanao; Los Banos, Mt. Makeling, Luzon; and N. W. Panay.

The clypeus has a small emargination in the middle below with a rounded tooth each side; a line from antennae to anterior ocellus; ocelli subequal, the posteriors a little nearer to each other than to eyes; third joint of antennae longer than fourth, second plus third almost equal to vertex width; pronotum short, only slightly arcuate behind; propodeum transversely rugose and carinate, hairy above; spines on mid and hind tibiae small, but distinct; long spur of hind tibia not one-half of basitarsus. In fore wings the marginal cell is almost triangular, and narrows the second submarginal at tip, it is about one-half its length from the wing-tip; second submarginal one-half longer than broad, base curved, end short, receiving the first recurrent near middle; third submarginal very much longer and larger than the second, somewhat narrowed above, receiving the second recurrent (slightly curved) at basal fourth; third abscissa of radius very much longer than second which is subequal to fourth; in hind wings the anal ends plainly before cubital fork; in fore wings the transverse nervure is almost or quite interstitial with the basal vein.

The male resembles that of *P. unifasciata*, but there is no pale on the clypeus, a pale line on each lower orbit, and lower side of basal antennal joint pale. Forewings with the narrow stigmal band; it can be separated from *P. unifasciata* in both sexes by the fact that in

P. unifasciata the lower side of the first submarginal cell is straight while in *P. nitidiventris* it is plainly a little curved, bending into the first discoidal cell. Clypeus hardly twice as broad as long, almost truncate below; a line from antennae to anterior ocellus; ocelli large, anterior not its diameter from the posterior, latter nearer to eyes than to each other; antennae slender, hardly crenulate toward tip, third joint scarcely longer than fourth; long spur of hind tibia about two-thirds of the basitarsus.

Pseudagenia nyemitawa Rohwer.

Described from Los Banos, specimens also from Mt. Makeling, Luzon; Cuernos Mts., Negros; and Island of Sibuyan.

Rohwer states that the clypeus is truncate; it is rounded in these specimens, much as in *P. makelingi*, but not so long or quite so pointed; the interocellar area is much swollen, and the ocelli in its base. In fact it differs from *makelingi* almost wholly in the swollen interocellar area, in the more rounded clypeus, and the minute spines on mid and hind tibiae are a trifle more distinct than in *makelingi*. The venation is the same as in *makelingi*.

Pseudagenia okawa Rohwer.

Described from Los Banos, specimens also from Mt. Makeling, Luzon; Kolambugan, Mindanao; Cuernos Mts., Negros; Island of Sibuyan; and Island of Samar.

Head and thorax with much moderately short erect hair, pleura also; propodeum with long erect hair above, basal abdominal segment with moderately long erect hair, apex and venter also hairy. Second and third antennal joints together hardly equal to vertex width; pronotum behind only slightly arcuate, mesopleura punctured like the propodeum; mid tibia with extremely small spines, but hind tibia practically without spines above; long spur of hind tibia about one-half of basitarsus. Fore wings with marginal cell about one-half its length from wing-tip; the second submarginal cell about two-thirds longer than broad, base quite oblique, receiving the first recurrent at middle; third submarginal much longer and larger behind, narrowed about one-third above, receiving the second recurrent vein beyond the basal third, but plainly before middle; in hind wings the anal ends at or almost at the cubital fork; in fore wings the transverse nervure is plainly (but not far) beyond the basal vein.

The male is similar in general appearance to the female, but more slender, the basal abdominal segment is mostly narrowed to a petiole;

the front tibia and tarsi are more or less pale; sometimes pale on lower inner orbits. The clypeus is plainly more than twice as broad as long, its lower edge gently rounded; the antennae are moderately slender, the third joint equal to fourth, and more than four times as long as second; the mesopleura and propodeum heavily punctate; long spur of hind tibia almost two-thirds of the basitarsus; venation as in the female.

Pseudagenia pardalice sp. nov.

♀ Head and thorax pale reddish, the clypeus more yellowish; abdomen more red brown; legs yellowish, but apical half of tarsi, apical half of hind femora, and most of the hind tibiae dark, spurs dark; antennae yellowish on first two joints, then brown; palpi pale yellowish; wings faintly yellowish, unmarked, stigma yellowish. A few hairs on vertex, and the propodeum hairy above, but more smooth than most species. Clypeus large, rounded below, but almost coming to a point in middle; ocelli moderately large, subequal, the posteriors scarcely diameter apart and much further from eyes; third joint of antennae very long and slender, longer than fourth, and of itself longer than vertex width. Pronotum deeply arcuate behind; propodeum but little arched, the fine striae very indistinct; the metanotum back of the postscutellum very broad and very plainly striate all the way over on sides; abdomen short, basal segment rather slender and with a moderately long pedicel, scarcely hairy near the tip, last segment shining; legs with distinct, but small spines on mid and hind tibiae, long spur of hind tibia one-half of basitarsus. Fore wings with marginal cell about one-half its length from wing-tip; second submarginal twice as long as broad, base curved, receiving the first recurrent at middle; third submarginal cell a little longer but not much wider behind than the second, receiving the second recurrent (scarcely bent) before end of basal third; second, third, and fourth abscissae of radius subequal; in hind-wing the anal ends much before the cubital fork.

Length 11 mm.; fore wing 9.5 mm.

From Sandakan, Borneo, one female.

Pseudagenia persephone sp. nov.

♀ Black, with sericeous pubescence, white on clypeus and lower face, and fairly prominent on the abdomen; white hair on head, pronotum, pleura, and propodeum; hind femora reddish, except the ends; antennae black; palpi brown; wings clear, unmarked, some-

times very faintly yellowish. Clypeus slightly, evenly rounded below, no point; a line from antennae to anterior ocellus; ocelli subequal, posteriors about as near eyes as to each other, ocellar area a trifle swollen; antennae short, third joint but little longer than the fourth, second plus third not equal vertex width; pronotum lightly arcuate behind; propodeum evenly arched, with furrow in middle, very finely striate, but much punctured, mostly behind. Abdomen with very short pedicel, convex, hairy on basal segment above, near tip, and on venter; mid and hind tibiae with very short, fine spines; long spur of hind tibia one-half of basitarsus. Fore wings with marginal cell more than one-half its length from wing-tip; second submarginal twice as long as broad, base curved, receiving the first recurrent vein just beyond the middle; third submarginal cell much longer and wider behind than the second, much narrowed above, receiving the second recurrent vein (scarcely curved) at basal third; third abscissa of radius plainly longer than second, which is little longer than fourth; in hind wings the anal ends almost or quite at the cubital fork.

Length 10 mm.; fore wing 9 mm.

From Dapitan, and Kolambugan, Mindanao; Sandakan, Borneo; and Puerto Princesa, Palawan.

This and *P. tagalensis* are apparently closely related to *P. borneana*, but neither are especially hairy, and the antennae in both species are wholly black. *P. persephone* differs from *P. tagalensis* in the shorter and less pointed clypeus, in shorter third joint of antennae, etc.

Pseudagenia pictoides sp. nov.

♀ Body black, clypeus whitish, with a faint median line, a yellowish line up each orbit about one-half way, lower face silvery; antennae yellowish, at least on basal part and below, above darker toward tip; palpi white; posterior border of pronotum whitish (in one specimen scutelli yellowish); some white pubescence on coxae, mesopleura, and tip of propodeum; legs yellowish or yellowish brown, the mid and hind tarsi and sometimes these tibiae and femora darker; wings clear, unmarked. Clypeus rather broad and short, but almost coming to a point in the middle below; face rather broad, a line from antennae to anterior ocellus; ocelli moderately large, anterior scarcely larger, posteriors nearer to each other than to eyes; third joint of antennae a little longer than fourth, second plus third not quite equal to vertex width; front with few hairs; pronotum almost angulate behind;

propodeum with long white hair above, no median groove, striae scarcely visible. Abdomen rather long and slender, with moderate pedicel, tip polished and hairy; mid and hind tibiae practically without spines, long spur of hind tibia about three-fifths of basitarsus. In fore wings the marginal cell is nearly two-thirds its length from wing tip; second submarginal cell more than twice as long as broad, base quite oblique and slightly curved, receiving the first recurrent vein near middle; third submarginal cell much longer and wider behind than the second much narrowed above, receiving the second recurrent (evenly curved) near basal third; third abscissa of radius a little longer than the second, which is about equal to fourth; anal in hind wing much before cubital fork.

Length 7.5 mm.; fore wing 7 mm.

From Island of Basilan; and Sandakan, Borneo.

Pseudagenia rizali sp. nov.

♀ Black, with a silvery pubescence strong on the face, clypeus, coxae, parts of pronotum, pleura, and propodeum behind; clypeus white, with a median black line from above (sometimes complete); apical half of palpi pale yellowish, also most of the mandibles; under surface of basal joint of mandibles yellowish; legs sometimes faintly ferrugineous, the mid and hind tibiae with a pale band at base; abdomen with the hind margin of the segments somewhat ferrugineous; wings clear. Clypeus rounded below, almost in a median rounded point; a line from antennae to the anterior ocellus; ocelli subequal, posteriors about as far from each other as from the eyes; antennae slender, long, third joint longer than the fourth, second plus third about equal vertex width; short white erect hair on vertex and on propodeum; pronotum slightly angulate behind; propodeum gently evenly arched, with a median line, punctured, not distinctly carinate; abdomen with hairs below and above near tip, somewhat silvery on the sides. Legs with scarcely distinct spines on mid and hind tibiae; long spur of hind tibia fully one-half of basitarsus. Fore wings with the marginal cell about one-half its length from wing-tip (not more); second submarginal cell fully twice as long as high, receiving the first recurrent vein near middle; third submarginal rather long and much wider toward the tip, receiving the second recurrent vein near basal third; second and third abscissae of radius about equal, and barely longer than the fourth; in hind wing the anal ends far before the cubital fork.

Length 8 to 9 mm.; fore wing 8 mm.

From Surigao, Davao, Dapitan and Iligan, all in Mindanao.

The male is similar to the female, the clypeus and mandibles white, clypeus sometimes with a small black spot above; under side of basal joint of antennae pale. Clypeus broad, truncate below; antennae slender, third joint equal to fourth; hind tibia with small spines above, long spur of hind tibia about two-thirds of basitarsus; basal segment of abdomen about one-half petiole; ocelli in a low triangle, posteriors three diameters apart; propodeum very rough; venation as in female.

Pseudagenia rohweri sp. nov.

♀ Body and coxae blue or faintly greenish, with silvery pubescence especially on clypeus, lower face, lower mesopleura, and tip of the propodeum; abdomen more black or faintly purplish; legs brown to black, femora sometimes faintly purplish; antennae black; palpi gray; fore wings clear, with a narrow dark band from tip of stigma back, but not across wing (sometimes faint); hind wings clear, scarcely darker at tip. Clypeus blunt pointed in middle below; a faint line from antennae to anterior ocellus; ocelli subequal, posteriors scarcely nearer to each other than to eyes; third joint of antennae longer than fourth, second plus third fully equal vertex width; pronotum arcuate, but not deeply, behind; middle of front of mesonotum with two short smooth lines; propodeum sloping, densely transversely wrinkled and rugose, and also with punctures behind, above white haired, short white hair on pleura. Abdomen with a short pedicel, long hair near tip and shorter on venter. Legs with minute spines on mid and hind tibiae, long spur of hind tibiae equal one-half of basitarsus. Forewings with marginal cell about one-half its length from wing-tip; second submarginal cell about one-half longer than broad, the base nearly straight, and oblique, receiving the first recurrent near middle; third submarginal a little longer than second, and one-half wider behind, receiving the second recurrent (slightly curved) at basal third; fourth abscissa of the radius equal or a little longer than the third; in hind wings the anal vein ends before the cubital fork.

Length 7.5 to 8.5 mm.; fore wing 6 to 7 mm.

From Dapitan and Iligan in Mindanao; and Mt. Makeling, Luzon.

Pseudagenia rufofemorata Ashmead.

Specimens from Mt. Makeling, Los Banos, Luzon; Cuernos Mts., Negros; Puerto Princesa, Palawan.

The mandibles are dark. The clypeus is rounded below, there is a line from antennae to anterior ocellus; the hind ocelli are a little nearer to each other than to the eyes; the third joint of the antennae plainly a little longer than fourth, second plus third not equal to vertex width; pronotum behind faintly angulate; propodeum hairy above, punctate behind, in certain views with faint transverse striae toward front; mid and hind tibiae practically without spines; long spur of hind tibia more than one-half of basitarsus. In the forewings the marginal cell not very long, about two-thirds the length from wing-tip, second submarginal cell about twice as long as broad, first recurrent received at middle, third submarginal a little longer, but much broader behind, narrowed one-third above, receiving the second recurrent at basal third; in hind wings the anal ends a little before cubital fork. What may be the male has a moderate petiole to abdomen, which is crossed near the middle by a yellow band, the legs are colored much as in the female, but usually with more black on the femora, the venation is the same as the female, the antennae are rather short, the third joint equal to the fourth, the clypeus is shaped much as in female, distinctly rounded below.

Pseudagenia tagalensis sp. nov.

♀ Body black, clothed with gray (rather than silvery) hair and pubescence; hair on propodeum, and pleura long and dense; the silvery patch on the lower mesopleura is not as distinct as in many species; palpi mostly brown and gray; antennae and legs black, front tibiae usually partly and the hind femora always reddish (except ends), often some reddish on front femora, and sometimes on mid femora; abdominal segments sometimes narrowly bordered with ferrugineous; wings clear or faintly yellowish, unmarked. Clypeus rounded below, not quite to a point in middle; ocelli subequal, the posteriors a trifle nearer to the eyes than to each other, interocellar area a little swollen; third joint of antennae long and slender, equal to vertex width, the latter rather narrow. Pronotum arcuate behind; propodeum sloping, heavily pitted, but in certain lights also transversely striate; metanotum back of postscutellum with a few striae; abdomen with basal segment triangular, above with short white hair, longer fine hair near tip and on venter. Legs with numerous distinct spines on mid and hind tibiae, mostly in rows above; long spur of hind tibiae one-half of basitarsus. Fore wing with marginal cell about one-half its length from wing tip; second and third submarginals long, the second

more than twice as long as broad, base nearly straight and very oblique, a little more so than in *P. blanda*, receiving the first recurrent vein plainly beyond the middle; third submarginal longer than second, and one-half wider behind, receiving the second recurrent at basal third; the third abscissa of radius a little longer than the second, the second a little longer than fourth; in hind wing the anal ends almost or quite at the cubital fork.

Length 11 mm.; fore wing 11 mm.

From Island of Samar; Island of Basilan; Dapitan, Zamboanga, and Davao in Mindanao; Los Banos, Luzon.

In appearance this is very similar to *P. tincta*, but in *P. tincta* the ocelli are in a narrow triangle, the lower mesopleura not swollen, and it is a *Phanagenia*.

The male agrees in general with the female. The clypeus is broad and truncate below, the third joint of antennae just a little longer than the fourth; a line from antennae to anterior ocellus; ocelli subequal, the posterior as near to eyes as to each other; long spur of hind tibia fully two-thirds of the basitarsus; venation as in female.

Pseudagenia unifasciata Ashmead.

Many specimens from Los Banos, Mt. Makeling, Baguio Benguet, Luzon; Surigao, Iligan, Davao, Dapitan, Kolambugan, Mindanao; Culasi, Panay; Cuernos Mts., Negros; Malinao, Tayabas; Island of Basilan, Island of Biliran; Island of Sibuyan; Puerto Princesa, Palawan; and Sandakan, Borneo.

This small species is very near to *P. celaeno* Sm., but the clypeus is more prominent below. There is often a spot on the transverse nervure. The posterior ocelli are much nearer to each other than to eyes; third joint of antennae a little longer than fourth, second plus third not or almost equal to vertex width, the propodeum is transversely carinate, most plainly in the middle, the metanotum back of postscutellum shows several striae; long spur of hind tibia not quite one-half of basitarsus. In the forewing the marginal cell is one-half its length from wing-tip; second submarginal cell one-fourth longer than broad, base curved, receiving the first recurrent vein near middle; third submarginal cell plainly longer below; but above no longer than second, receiving the second recurrent (much curved) at basal third; in hind wings anal ends plainly before the cubital fork. There is much variation in size; the larger specimens showing the ridges on propodeum plainly, in small specimens these are very faint.

The male is more slender; the first segment of abdomen is entirely petiolate. The body is black, with much white pubescence; the lower margin of clypeus is pale and the sides narrowly, the pale extending up on the lower face; the under side of basal joint of antennae pale; the first and mid basitarsi are usually pale, and the spurs paler than the tibiae. The wings have the same narrow stigmal band as the female; the clypeus is about twice as broad as long, its lower margin truncate, the antennae have the third joint plainly a little longer than the fourth; the long spur of hind tibia nearly three-fourths of basitarsus; the venation is like the female.

MINAGENIA subgenus nov.

This is a very distinct section of *Pseudagenia*, and should be named. The two species are small; the clypeus is broad, slightly rounded below, but almost truncate; the abdomen is hardly if at all petiolate, and in the male the basal segment is flattened; in the male the antennae are short, in one species much like *Meragenia*; in both sexes the genus differs from all *Pseudagenia* in that the median vein of fore wing reaches the outer margin, it is very fine, but distinct; in this respect it resembles *Deuteraenia*. Type *P. brevicornis*. The two species may be separated as follows:

1. Second submarginal cell usually longer than broad, third cell shorter; third antennal joint fully three times as long as second; abdomen with short pedicel; basal part of antennae pale beneath. *assimilis*
 Second submarginal cell very short, as also the third; third antennal joint not three times the second; no pedicel to abdomen; antennae black beneath. *brevicornis*

Pseudagenia (Minagenia) brevicornis sp. nov.

♀ Dull black, abdomen more shining; fore wings clear, with two dark bands, narrow one over the basal vein, and a broad one beyond the stigma. A very few erect hairs on vertex, some very short and fine hairs at tip of abdomen, otherwise without hair. Clypeus short, broad, truncate below; face scarcely narrowed above; a line from antennae goes only one-half way up; ocelli in a rather broad triangle, the posteriors fully as near eyes as to each other; antennae very short and thick, last joint noticeably short and broad, third joint no longer than fourth, and not three times as long as second; pronotum arcuate behind; propodeum slightly arched, no distinct median groove, no distinct striae, no hairs above. Abdomen not pedicellate, somewhat

compressed near tip; mid and hind tibiae without scarcely noticeable spines; long spur of hind tibia almost one-half of the basitarsus. Fore wings with the marginal cell two-thirds its length from wing-tip; median vein reaches to margin; second submarginal cell short, hardly longer if any than broad, oblique, bulging below, receiving the first recurrent at or beyond middle; third submarginal cell also short, but about as long as second, outer border convex, receiving the second recurrent vein beyond middle; third abscissa of radius subequal to second, both shorter than the fourth; in hind wings the anal ends before the cubital fork; in fore wing the transverse nervure is almost or quite interstitial with the basal.

Length 5 mm.; fore wing 4.5 mm.

From Manila and Mt. Limay, Luzon; and Surigao, Mindanao.

The male has extremely short and thick antennae (like a *Meragenia*); the dark cloud in fore wing may extend out to the tip; the second and third submarginal cells are both very short; the recurrent veins end beyond the middle in both; the long spur of hind tibia about two-thirds of the basitarsus.

Pseudagenia (Minagenia) assimilis Smith.

Described from Celebes, these specimens fit Smith description so well I believe the identification sure. They are from Los Banos, Mt. Banahao, Mt. Makeling, Luzon; Surigao, Dapitan, Butuan in Mindanao; Island of Sibuyan; Island of Basilan; and Imugin, N. Viscaya.

♀ The clypeus is broad, truncate below; the antennae are moderately long, the third joint a trifle longer than fourth, and about three times as long as the second; a faint line from antennae to the anterior ocellus; ocelli subequal, the posteriors a little nearer to each other than to the eyes; pronotum angulate behind; propodeum evenly rounded, no distinct median groove, nor transverse carinae, no hair above. Abdomen with the basal segment with a short pedicel, some moderately long hair at tip; mid and hind tibiae without distinct spines, long spur of hind tibia about two-fifths of basitarsus. In fore wing the marginal cell is almost one-half its length from wing tip; the second submarginal cell is about one-half longer than broad, receiving the first recurrent vein at middle; the third submarginal cell shorter than the second, hardly longer than high, receiving the second recurrent vein at or before the middle; third abscissa of radius very much shorter than the second, which is equal or almost equal to the

fourth; in hind wing the anal ends before cubital fork; in fore wing the transverse nervure is a little beyond the basal.

Length 6 to 7 mm.

The male of this is represented by several specimens from Baguio Benguet, Mt. Makeling, Luzon; and a few from Dapitan and Surigao in Mindanao. The abdomen has no distinct pedicel, the basal segment narrowed to base and flattened; the second submarginal cell is extremely short and oblique; the antennae are not particularly short nor thick; the colors are as in the female.

DINAGENIA gen. nov.

Body more robust than in *Pseudagenia*, the basal abdominal segment fully as long as the second, and the second and the third not enlarged. Head broad, eyes large, face somewhat narrowed above and below; palpi are short like those of the *Cryptocheilinae*, the tips of the joints somewhat enlarged. The legs have only very weak spines on the mid and hind tibiae, and the hind tibiae are not as elongate as in *Pseudagenia*; the claws are cleft; the last tarsal joint smooth beneath. The venation is similar to that of many species of *Pseudagenia*.

Dinagenia apollo sp. nov.

♀ Body black, golden pubescence on head, pronotum, mesonotum, scutelli, lower mesopleura, propodeum, and apical segment of abdomen. The lower part of clypeus is usually yellowish, as also the pronotum, mesonotum, and scutelli; the antennae are yellowish, the tips darker; the palpi yellowish; the legs also, the tips of the mid and hind tarsal joints often dark. The wings are yellow, with a narrow dark apical border to the front pair, and less distinctly on the hind wings, the stigma and veins yellowish. The head, pronotum, and front coxae have short erect hair, and some on the sides and end of propodeum. The clypeus is broad, broadly truncate below; the ocelli are rather large and subequal, posteriors nearer to eyes than to each other; third joint of antennae not as long as the fourth, second plus third nearly or quite equal to vertex width; posterior border of the pronotum rather deeply arcuate; propodeum nearly level at first, then arched, strongly, transversely carinate, and with a median furrow. Abdomen rather slender, fusiform, hairy at tip; legs moderately stout, mid and hind tibiae with scattered short spines, some in rows above; long spur of hind tibia nearly one half of basitarsus.

Forewings with marginal cell about two-thirds its length from wing tip, stigma pointed behind; second submarginal cell a little more than twice as long as broad, base curved, receiving the first recurrent near middle; third submarginal but little longer than second, but wider behind, considerably narrowed above, receiving the second recurrent vein (scarcely curved) somewhat before middle; third abscissa of radius, about as long or a little shorter than second, which is usually subequal to the fourth; in hind wings the anal ends at the cubital fork.

Length 11 to 18 mm.; fore wing 10 to 15 mm.

From Surigao and Iligan in Mindanao, and the Island of Samar.

What appears to be the male (from Iligan) is 9.5 mm. long, apical half of antennae dark; besides the dorsum of thorax, the dorsum of abdomen is largely yellow, but darker toward tip. The legs are yellow; wings less yellow than in female; the antennae short, thick, and strongly crenulate; the clypeus truncate; head, pronotum, and propodeum more hairy than in female, the legs somewhat hairy; long spur of hind tibia nearly two-thirds of basitarsus; venation similar to that of the female.

TUMAGENIA gen. nov.

Resembling *Pseudagenia*, palpi elongate; hind tibia practically without spines; second discoidal cell square at base; clypeus triangular below; the head is broad, broader than usual in *Pseudagenia*, the orbits scarcely incurved above; the venation is similar to *Pseudagenia*, but the stigma is pointed behind. It differs from *Pseudagenia* and all allied genera in having a pair of large elongate humps occupying most of the front from antennae to the ocelli.

Tumagenia iris sp. nov.

♀ Head shining black, tip of clypeus yellowish; mandibles and palpi white; antennae brown; thorax reddish yellow; legs yellowish, tarsi brown, mid and hind femora and tibiae with a black band at tip; abdomen shining black; wings clear, with a broad brown band across from back of marginal cell. Almost wholly without erect hair, a few on vertex and pronotum, and some at tip of abdomen. Clypeus projecting in middle below to a rounded point; ocelli small, subequal, posteriors more than twice as near to each other as to the eyes; third joint of antennae scarcely longer than fourth, second plus third not equal to vertex width; pronotum arcuate behind; propodeum low, with a median furrow, minutely rugulose, but scarcely striate; the metanotum back of postscutellum with a few distinct striae; abdomen

with a moderately long pedicel, convex, not very long; mid tibiae with a few very minute spines above, on hind tibiae scarcely visible, long spur of hind tibia fully two-thirds of basitarsus. Fore wings with marginal cell about two-thirds of its length from wing-tip; second submarginal one-half longer than broad, both ends oblique, receiving the first recurrent vein at middle; third submarginal a trifle longer below, but shorter above than the second, receiving the second recurrent (moderately curved) before the end of basal fourth; third abscissa of radius much shorter than the second, which is about equal to the fourth; in hind wings the anal ends plainly before the cubital fork.

Length 6 mm.; fore wings 5 mm.

From Baguio Benguet, Los Banos, Luzon; and Sandakan, Borneo.

DEUTERAGENIA.

Deuteragenia thias sp. nov.

♀ Black, when fresh clothed with yellowish or golden hair, especially dense on clypeus, older specimens lack this hair completely; in fresh specimens legs are more or less yellowish, older ones are brown to black; antennae brown, joinings darker; apical part of mandibles, and the palpi pale; wings clear, a narrow dark band over basal and transverse nervures, a broader cloud in part of the marginal and second and third submarginal cells, this latter mark may be faint in some old specimens. Clypeus rounded below, but almost truncate in middle; face gradually narrowed above; ocelli in narrow triangle, posteriors fully as close to eyes as to each other; third joint of antennae longer than fourth; second plus third more than equal vertex width; the hair basket under head of yellowish bristles; a few erect hairs on vertex; pronotum quite long, arcuate behind; propodeum evenly arched, median line faintly indicated, surface not striate, but minutely shagreened. Abdomen with rather long pedicel, strongly convex, hairy toward tip; mid and hind tibiae with only microscopic traces of spines; long spur of hind tibia about two-fifths of basitarsus. Fore wings with marginal cell more than one-half its length from wing-tip; second submarginal cell one-half longer than broad, both ends oblique, receiving the first recurrent beyond middle; the third submarginal shorter than the second below and only one-half as long above, about as broad as long, receiving the second recurrent (which is much curved above) close to its base; third abscissa of radius shorter than second and this only about one-half of the fourth; in hind wing the anal ends a long ways before the cubital fork.

Length 9 to 10 mm.; fore wing 8 mm.

From Mt. Banahao, Luzon; and Butuan, and Iligan, Mindanao; Imugin, N. Viscaya.

There is much variation in the extent of the stigmal mark in the fore wings, sometimes almost lacking; the mouth parts may be almost wholly yellowish, including the lower part of the clypeus, and the legs may be largely pale.

CONAGENIA gen. nov.

I propose this name for those species of *Pseudagenia* in which there is a median nose-like projection to the lower border of the clypeus in the female.

Pseudagenia williamsi Rohwer is the type.

CONAGENIA.

- | | |
|---|------------------|
| 1. No bands on wings | <i>ingenua</i> |
| Bands on wings | 2 |
| 2. Thorax reddish | <i>aegina</i> |
| Thorax black | 3 |
| 3. Third submarginal cell twice as long as broad; larger species | <i>nasuta</i> |
| Third submarginal cell not twice as long as broad | 4 |
| 4. Tip of wing faintly shaded; spot on basal vein small and faint | <i>williamsi</i> |
| Tip of wing clear; mark over basal vein distinct | <i>smithi</i> |

Ingenua and *nasuta* occur in Celebes, the latter also at Singapore.

Conagenia williamsi Rohwer.

Very common in Luzon, Los Banos, Mt. Makeling, Baguio Benguet; Puerto Princesa Palawan; Surigao, Butuan, Dapitan, in Mindanao; Malinao, Tayabas, Cuernos Mts., Negros; N. W. Panay.

Very close to *C. smithi* and perhaps not distinct; but the fainter marks, especially on the basal vein, the faintly dark wing-tip, generally smaller size; and a few slight differences in venation, the third submarginal cell less narrowed above; marginal cell proportionally shorter; second recurrent ends a little further out; and the long spur of hind tibia is a little shorter.

What is probably the male of this species according to size, markings and distribution is a small black form with wing bands as in the female, the apical one sometimes extending to the tip, nearly always some dark in the third submarginal cell; the last segment of abdomen is white above, in some there is a pale line in each lower orbit; the spurs (at least long ones) are distinctly white. The clypeus is almost

twice as broad as long, rounded below; the ocelli in a narrow triangle, the posteriors are nearly or quite twice as near each other as to the eyes; the antennae are slender, beyond basal part somewhat crenulate; the abdomen is very slender, the basal segment practically all petiole; long spur of hind tibia two thirds of basitarsus. In the fore wings the second and third submarginals subequal, each a little longer than broad, first recurrent ends near middle, the second recurrent ends close to the base (as in female). Its chief difference from the female is the white spurs.

Specimens from Los Banos, Mt. Makeling, Luzon; Imugin, N. Viscaya; Iligan, Surigao, Davao, Butuan, Zamboanga, in Mindanao; Cuernos Mts., Negros; Puerto Princesa, Palawan; Tangcolan, Bukidnon; and Sandakan, Borneo.

Conagenia smithi sp. nov.

♀ Black; fore wings clear, with two dark bands, a narrow one over basal vein, and a very broad one back of stigma; clypeus and lower face with silvery white pile. Clypeus very convex, with a large median tooth below; ocelli subequal, posteriors much nearer to each other than to eyes; third joint of antennae longer than fourth, second plus third almost equal vertex width; pronotum arcuate behind; propodeum transversely carinate; abdomen short and convex, hairy at tip and on venter; mid and hind tibiae with only very small spines; long spur of hind tibia almost one-half of basitarsus. Fore wings with marginal cell fully one-half its length from wing-tip; second submarginal cell one-half longer than broad, base curved, receiving the first recurrent at middle; third submarginal cell hardly if any longer below than the second, and much narrowed above, receiving the second recurrent vein (much bent above) close to the base; third abscissa of radius much shorter than second, which is shorter or subequal to fourth; in hind wing the anal vein ends before cubital fork.

Length 6 to 7 mm.; fore wing 5.5 to 6.8 mm.

From Los Banos, Mt. Makeling, and Baguio Benguet in Luzon; Dapitan, Davao, and Surigao in Mindanao; Tangcolan, Bukidnon, Island of Sibuyan; Island of Basilan; Puerto Princesa, Palawan; and Sandakan, Borneo.

Close to *C. nasuta* Smith from Southern Celebes. From Singapore I have what I believe is *C. nasuta*; it averages larger (10 mm.); the tip of wing is more distinctly white; the third cubital cell is much longer, less narrowed above, the second recurrent received near

basal fourth (in *smithi* nearer to base). Either of these would fit Smith's description except that the Philippine form is smaller than the size given by the describer.

What may be the male of this species agrees with the female in having two bands on the fore wing, and in that the basal and transverse veins are almost or quite interstitial. There is a faint yellowish mark in each lower orbit; the basal joint of antennae is pale beneath; palpi gray; last segment of abdomen white above; the spurs pale. The clypeus is hardly one-half broader than long, lower margin rounded, upper sides very oblique; antennae slender, somewhat crenulate toward tip; ocelli moderately large and close together; long spur of hind tibia is fully two-thirds of basitarsus; the venation is similar to that of female, but the third submarginal is usually shorter than the second (in female usually equal).

Conagenia aegina Smith.

Specimens from Los Banos, Mt. Makeling, Luzon; Iligan, Dapitan, Butuan, Surigao, Kolambugan, and Zamboanga, Mindanao; Island of Samar, Island of Sibuyan; N. W. Pany; and Sandakan, Borneo.

Smith says nothing about the process to the clypeus, and also says the hind femora are yellow; in all these specimens the hind femora are black. This is, however, the species treated by Bingham as *C. aegina* and I presume he saw the type; however there is some doubt if this be Smith's species. The three other forms that have the red thorax also have black hind femora.

♀ Clypeus wedge-shaped, projecting below in a very distinct median process; a line from antennae to anterior ocellus, faint above; ocelli subequal, in nearly equilateral triangle, the posteriors very much nearer to each other than to the eyes; third joint of antennae long and slender, of itself about equal to vertex width; propodeum only slightly arched, near level, transversely wrinkled, only very short hair above; abdomen with short pedicel, tip with white hairs, pygidium shining black; mid and hind tibia with only very small spines, long spur to hind tibia not one-half but fully two-fifths of basitarsus; fore wings with marginal cell hardly one-half its length from the wing-tip; second submarginal cell fully one-half longer than broad, base much curved, receiving the first recurrent at middle; third submarginal a little shorter below than the second, narrowed one-half above, receiving the second recurrent vein (bent in middle) a little before end of basal third; third abscissa of radius much shorter than

the second, and this shorter than the fourth; in hind wings anal much before cubital fork; in fore wings transverse nervure a little beyond basal vein. The male is black except the pronotum, mesonotum, upper mesopleura, scutellum and sometimes part of metanotum red, last segment of abdomen white above; spur white; lower side of basal joint of antennae pale; wing marked as in female. The antennae long and slender, tip acute; clypeus rounded below; long spur of hind tibia a little more than one-half of basitarsus; abdomen small, somewhat compressed, basal segment is mostly pedicel; venation as in female.

CALAGENIA gen. nov.

The three forms I place here are remarkable for having the lower mesopleura swollen cone-like, at once reminding one of *Macromeris*. Head and venation similar to *Pseudagenia*.

C. hermosa is the type.

Synopsis of the species.

- | | |
|---|-------------------|
| 1. Forewings yellowish, legs yellow | 2 |
| Forewings nearly clear, legs dark or greenish; mesopleural process very sharp; body greenish | <i>chloranthe</i> |
| 2. Wings only slightly yellowish, tip faintly dark; thorax greenish blue; mesopleural process rounded | <i>hermosa</i> |
| Wings deeper yellow, no dark tip; body violaceous; mesopleural process rather sharp | <i>violacea</i> |

Calagenia chloranthe sp. nov.

♀ Bluish to greenish on body, coxae, femora, and tibiae; tarsi brown, antennae black; palpi brownish; wings clear or faintly yellowish, unmarked. Face and clypeus with silvery pubescence, some also on pleura and propodeum. Clypeus coming to a blunt point in middle below; a short line above antennae, not going to ocellus; ocelli rather small, subequal, posteriors plainly closer to each other than to eyes, interocellar area somewhat swollen, but more prominent just behind ocelli; a few erect hairs on vertex; third joint of antennae much longer than fourth, second plus third nearly equal vertex width; pronotum angulate behind; propodeum arched, strongly, transversely wrinkled, with long hair above; metanotum back of postscutellum with striae; lower part of mesopleura in front of mid coxae greatly swollen into an almost sharp cone (similar to *P. violacea*). Abdomen hairy near tip, basal segment moderately slender in front, last segment above violaceous; legs long and slender, mid and hind

tibiae show scarcely a trace of spines; long spur of hind tibia not one-half of basitarsus. Forewings with marginal cell more than one half its length from wing-tip; second submarginal not twice as long as broad, base curved, receiving the first recurrent near middle; third submarginal much longer than second and nearly twice as broad behind, receiving the second recurrent (evenly curved) at basal fourth; third abscissa of radius much longer than the second, which is about equal to the fourth; in hind wing the anal ends much before the cubital fork.

Length 9 mm.; fore wing 8 mm.

From Baguio Benguet, Luzon, one specimen.

Calagenia hermosa sp. nov.

♀ Black, the head and thorax with a strong greenish or bluish iridescence, on the face it is somewhat obscured by fine pubescence, the abdomen black and polished; antennae yellowish, the joinings of joints dark; legs (except coxae) yellowish, the tips of tarsi brown; wings yellowish, slightly darker at extreme tips; spurs brown. Clypeus in middle below with a rounded point; ocelli in equilateral triangle, posteriors plainly nearer to each other than to the eyes; third joint of antennae plainly longer than fourth, second plus third scarcely equal to vertex width; pronotum arcuate behind; propodeum sloping, with moderately long hair, transversely carinate, with a broad, shallow furrow down the middle; lower mesopleura rather strongly swollen in front of mid coxae. Abdomen shining, convex, with a few hairs toward the tip, and very short ones on venter; legs smooth, no spines on hind tibiae, mid tibiae with a few extremely minute ones near the tip above, long spur of hind tibia about one half of the basitarsus. Wings with yellow stigma; fourth abscissa of radius much shorter than third; second submarginal cell about twice as long as broad, third submarginal very much larger, especially toward tip where it is more than twice as wide as at base, first recurrent vein ends near middle of the second submarginal, second recurrent (evenly curved) ends near base of the third submarginal cell; in hind wing the anal ends much before the cubital fork.

Length 7.5 mm.; fore wing 7 mm.

From Galog River, 6 Nov., 6000 ft. and Mainit River, 14 Sept., 6000 ft., both on Mt. Apo, Mindanao (Clagg).

The male is more slender, with black body and sericeous pubescence; on face and clypeus golden pubescence; antennae as in female, the tips

brown; wings colored as in female, but the second submarginal brown and somewhat clouded near by; propodeum not carinate; clypeus convex, truncate in front.

From Seliban River, 11 Sept., 7000 ft., Mt. Apo, Mindanao (Clagg).

Calagenia hermosa var. *violacea* n. var.

Head and thorax strongly violaceous; wings a deeper yellow, no dark at tip; propodeum without the shallow median groove; lower part of mesopleura more protuberant than in typical form.

From Calian, 31 Dec., Davao Province, Mindanao (Clagg).

LOPHAGENIA gen. nov.

A section of *Pseudagenia*; the mesonotum longitudinally striate behind, scutellum elevated in the middle, and longitudinally striate on sides; clypeus deeply rounded below; basal and transverse nervure in forewings almost interstitial, the venation generally like *Pseudagenia*, but the third submarginal extends beyond the marginal cell, and the end bends back very strongly above middle; stigma blunt behind. Abdomen plainly short pedicellate, second and third segments much enlarged; mid and hind tibiae with only very minute spines, the hind tibia as long as usual in *Pseudagenia*; palpi elongate as *Pseudagenia*; head fairly broad, pronotum moderately long, much rounded in front.

Type *Pseudagenia erigone* Bingham.

Lophagenia erigone Bingham

Specimens from Surigao, Davao, and Dapitan, Mindanao; and Island of Sibuyan.

♀ Third joint of antennae very long, about equal to vertex width; posterior ocelli much nearer to each other than to eyes; propodeum striate, but behind largely irregularly rugose; the marginal cell is triangular, widest at end of the second submarginal cell. The third submarginal is of peculiar shape, long below, the outer side at first sloping outward then turns at almost a right angle up to the radius, it receives the second recurrent (much bent below) before end of the basal third; in hind wing the anal ends a little before cubital fork; long spur of hind tibia hardly two-fifths of basitarsus. The male is very similar but more slender, the thorax of the same granular and punctured appearance as in female; the basal abdominal segment wholly a pedicel; the long spur of hind tibia more than one-half

basitarsus; the antennae slender, and scarcely crenulate near tip; the head and thorax more hairy than in female; wing marks and venation as in female.

Length 10 mm.

From Davao and Dapitan, Mindanao.

MERAGENIA gen. nov.

Mid and hind tibiae with only minute traces of spines; palpi elongate as in *Pseudagenia*; pronotum very long, nearly as long as mesonotum, and in front the anterior lateral angles are prolonged so that the front of pronotum is nearly straight, or almost concave; the entire thorax and propodeum is deeply punctured and roughened; the mesonotum has a median smooth area, widened in front; the claws have a small tooth toward tip. The antennae are short, the fourth joint is very short, the clypeus is short and truncate below; the transverse nervure is usually a little beyond the basal.

Type is *Pseudagenia imitator* Ashmead; this species is very close to *P. stulta* Bing. from India.

Synopsis of the species.

1. Thorax reddish, wings with two bands; transverse nervure almost or quite interstitial with the basal. *rufithorax*
 Thorax black, wings clear or with one dark cloud; transverse nervure plainly beyond the basal 2
2. Hind femora (and usually mid also) reddish, and paler than the body. *imitator*
 Hind femora (and mid also) blackish brown, about as dark as body *nigripes*

Meragenia imitator Ashmead.

Many specimens, some nearly one-half longer than the type. They come from Mt. Makeling, Los Banos, Luzon, Surigao, Kolambagan, Zamboanga, Davao, Mindanao; Cuernos Mts., Negros; Tangcolan, Bukidnon.

In the type there is a small cloud behind stigma; this is present in some, but fades out, and most specimens there is not a trace of it; in a few the wing is slightly fuscous throughout. Usually the mid and hind coxae are reddish yellow, but in some one or both pairs are black or partly so. In the larger specimens the face appears to be proportionally more narrow but this varies among the smaller speci-

mens. The antennae are short, and the joints are as in *M. nigripes* and *M. rufithorax*, but the second and third usually hardly equal to vertex width; the long spur of hind tibia is one-half or a little more than half of the basitarsus. The male is similar, the abdomen with a longer pedicel, the antennae plainly crenulate; the thorax more hairy than in the female. The type was described as having a distinct cloud in the forewings; a few such occur in this lot, but I can find no very definite structural character to separate them from the common clear-winged form; the propodeum shows, in the typical form, more definitely transverse rugae or wrinkles, but it is somewhat variable. However, since all of these specimens with the cloud come from Los Banos, or near by, and although there are many from Mindanao and other islands none are clouded, it does seem to be a local form. I shall therefore call the specimens with unmarked wings a variety—*Meragenia imitator clara*.

Meragenia rufithorax sp. nov.

♀ Head and abdomen black, thorax reddish; antennae and legs black to brown; wings somewhat yellowish, fore pair with two dark bands, one over the basal, the other from stigma and basal part of marginal cell back into the second and third submarginal, and the second discoidal cells, not reaching across. Body with scarcely any erect hair, except on the sides and back of propodeum. Clypeus short, slightly rounded below; face scarcely narrowed above; anterior ocellus larger than the others, posteriors nearer to each other than to the eyes; antennae very short, third joint much longer than the fourth, latter extremely short, second plus third not equal vertex width; pronotum behind scarcely arcuate in middle; propodeum at first nearly level, then curving down to tip, densely rugulose, somewhat transversely wrinkled in some places, no median groove. Abdomen fusiform, with moderate pedicel, tip somewhat hairy; mid and hind tibia with only the most minute spines, long spur of hind tibia almost one-half of basitarsus. Fore wing with marginal cell almost triangular, about one-half its length from wing-tip; second submarginal not twice as long as broad, base rounded, receiving the first recurrent before the middle; third submarginal not near as long as second below, and above very much narrowed, sometimes almost triangular, receiving the second recurrent (slightly curved) before middle; third abscissa hardly one-half or less of second, fourth nearly equal to second and third together; in hind wing anal ends plainly

before cubital fork; in fore wing the transverse nervure is almost or quite interstitial with basal.

Length 6.5 to 9 mm.; fore wings 6 to 8 mm.

From Los Banos, and Mt. Makeling, Luzon.

From Los Banos are several specimens of a male *Meragenia* which is not either *imitator* nor *nigripes*, and so may well be male of *rufithorax*. However, the entire body is black, no sign of reddish on thorax, the legs and antennae black; the wings clear, usually with two dark bands as in the female (a few show no marks); the venation is like that of the female. Clypeus more than twice as broad as long, slightly rounded below; no line to anterior ocellus; ocelli subequal, the posteriors a little nearer to each other than to the eyes; antennae short and thick as in other species; long spur of hind tibia about three-fifths of basitarsus. In the fore wings the venation is similar to that of the female, but the third submarginal cell is as long or longer than the second. One specimen shows the pronotum and mesonotum reddish, but apparently does not differ in structure.

Meragenia nigripes sp. nov.

♀ Close to *M. imitator* Ashm., but without the red on legs. The wings usually with a large cloud, sometimes from basal vein out to end of the second submarginal and second discoidal cells, or it may be almost or quite absent. Clypeus truncate below; face somewhat narrowed above; the ocelli close together, the posteriors closer to each other than to the eyes; the third joint of antennae longer than fourth; second plus third almost equal vertex width; pronotum nearly straight across behind; propodeum densely rugoso-punctate, short haired on sides and behind. Abdomen fusiform, hairy at tip; mid and hind tibiae with only a few very minute spines; long spur of hind tibia about one-half the basitarsus; fore wings with marginal cell almost one-half its length from wing-tip; second submarginal about twice as long as broad, base oblique, receiving the first recurrent slightly before the middle; third submarginal a little longer than the second and fully one-half wider behind, receiving the second recurrent (evenly curved) near basal third; third abscissa of radius plainly longer than second, which is about equal to fourth; in hind wings anal much before cubital fork.

Length 6.5 mm.; fore wing 5.5 mm.

From Los Banos and Mt. Makeling, Luzon; Tangcolan, Bukidnon; Malinao, Tayabas; and Surigao, Mindanao.

PHANAGENIA.

I have made this genus for certain American forms possessing spines on the under side of the last tarsal joint. As a rule these forms have larger spines on the hind tibia than in *Pseudagenia*, to which they are closely related.

P. bombycina Cress. is the genotype.

Synopsis of the species.

- | | |
|--|-----------------------|
| 1. Fore wings almost wholly black, body black..... | <i>negrilos</i> |
| Fore wings mostly pale..... | 2 |
| 2. Fore wings clear, unmarked..... | 3 |
| Fore wings with bands or spots..... | 4 |
| 3. Hind femora reddish, body blue..... | <i>guerini</i> |
| Hind femora black, body black..... | <i>comes</i> |
| 4. Legs yellowish..... | 5 |
| Legs black..... | 6 |
| 5. Wings with apex broadly black..... | <i>frauenfeldiana</i> |
| Wings with apex white, but brown before it..... | <i>chrysosoma</i> |
| 6. Ocellar area swollen; wings faintly yellowish, two bands on wings;
larger species..... | <i>callisto</i> |
| Ocellar area not swollen; wings not yellowish, basal band of wings very
faint or absent; smaller species..... | <i>banoensis</i> |

P. tincta of India will separate from *P. guerini* in having a black body and not swollen interocellar area.

Phanagenia chrysosoma Rohwer.

Described from northern Mindanao, it is very common on that island, specimens come from Zamboanga, Butuan, Kolambugan, Iligan, Surigao, and Galog River, Mt. Apo, 6000 feet, 12 Sept. (Clagg); also from Los Banos, Mt. Makeling, Mt. Banahao, Luzon; Cuernos Mts., Negros; Island of Biliran; Island of Basilan; Island of Samar; and N. W. Panay.

♀ Clypeus large, convex, well rounded below, in the middle with a small point; ocelli subequal, posteriors a little more than diameter apart, plainly farther from the eyes; third joint of antennae longer than the fourth, second plus third fully equal vertex width; pronotum behind deeply arcuately emarginate, sometimes almost angulate; propodeum shows a broad median furrow or depression, coming to a point behind, surface obsoletely transversely wrinkled, sometimes quite plainly, practically no erect hair above. Abdomen with a distinct petiole, with some long hair at tip, little on venter, pygidium

long, polished, above narrowed to a point; mid and hind tibiae with many short yellowish spines, most of those above in rows; long spur of hind tibia from one-third to two-fifths of the basitarsus. In fore wings the marginal cell is fusiform, about one-half its length from wing-tip; the second submarginal cell one-half longer than broad, base curved, receiving the first recurrent vein just beyond the middle; third submarginal much longer and larger behind than the second, about one-fourth narrowed above, receiving the second recurrent (lightly curved) at basal third; third abscissa of radius much longer than the second which in turn is plainly longer than the fourth; in hind wings the anal ends much before the cubital fork; in fore wings the transverse nervure is about one-half its length or more beyond the basal vein. There is much variation in the color of the body; the clypeus is usually yellow, and usually some yellow or reddish on the mesonotum and scutellum, and frequently the abdomen is more or less reddish or entirely so. Those specimens in which this invasion of red color has gone the farthest and the abdomen is wholly rufous above, as well as a large reddish (or yellowish) spot in middle of the propodeum may be designated as a variety, *Phanagenia chrysosoma* var. *dorsata*. Their wings are more yellow than in the other specimens.

Males with yellow legs, yellow or partly yellow antennae, with a white tip to wing beyond the dark cloud are probably males of this species. The clypeus is not very long, and is yellow only along the lower margin, the lower orbits are also pale. All are from Luzon.

No. 6 of the key may also belong to this species, or perhaps the male of *Deuteragenia thias*, which also has a white wing-tip. No. 6 differs from the Luzon specimens chiefly in having a longer clypeus which is entirely yellow, and a yellow spot in each lower orbit; the legs are hardly as yellow as the others, and the antennae often darker. They are mostly from Mindanao. *Phanagenia* is common in both islands.

Phanagenia sp. ♂ No. 7.

This is black; the under side of the basal joint of antennae pale, the palpi pale, the front tarsi are often yellowish; the fore wing shows a large stigmal cloud, beyond which the wing is white; last segment of abdomen white above, sometimes the lower margin of clypeus is pale, and there is a pale line in lower orbits. It may be that these are also the males of *P. chrysosoma*, the venation and wing marks the same, but legs and antennae more black; if they do not belong to *chrysosoma* I can not match them with any other females.

Phanagenia frauenfeldiana Saussure.

From Zamboanga, Mindanao; and Mt. Makeling, Luzon. Bingham in Fauna India has also described this, but Saussure's original description is more complete. The posterior ocelli are almost as near eyes as to each other; the third joint of the antennae is plainly longer than the fourth, second plus third equal vertex width; the metanotum back of postscutellum is very plainly striate; the long spur of hind tibia only about two-fifths of the basitarsus. The marginal cell of fore wing is fully two-thirds of its length from the wing-tip, the third submarginal is about as long as high; in the hind wings the anal is interstitial with the cubital fork.

Phanagenia banoensis Rohwer.

Los Banos, Mt. Makeling, Luzon; Tangcolan, Bukidnon; Cuernos Mts., Negros; Dapitan, Davao, Kolambugan, Mindanao; Sandakan, Borneo. In some specimens there is also in fore wings a small dark mark on the transverse nervule. The marginal cell is more than one-half its length from wing-tip; the second submarginal one-half longer than broad, base curved, receiving the first recurrent vein near middle; third submarginal cell plainly longer than second below, about one-third narrowed above, receiving the second recurrent (evenly curved) before end of the basal third; in hind wings the anal ends plainly before the cubital fork.

♂ There is, I think, no doubt about these. The wings have the faint dark band quite narrow as in the female. They are very slender, with long legs and antennae, and a strongly pedicellate abdomen. The clypeus has a broad white mark on each side which extends up the lower orbits, and there is a white spot on the mandibles, the under side of the basal antennal joint is also white, and usually white on front coxae; the spurs are dark, each segment of abdomen has a narrow apical margin pale, and the last segment is white above. The clypeus is about twice as broad as long, slightly rounded below; the long spur of the hind tibia about two-thirds of the basitarsus; venation as in female.

Phanagenia callisto Smith.

One from Mt. Banahao, Luzon.

This well-marked species has been described by Bingham in Fauna Indica. The clypeus scarcely comes to a point below; the face is but little narrowed above; there is an interocellar hump, and the subequal

ocelli are at its base, the posteriors only a little nearer to each other than to the eyes; the third joint of antennae much longer than the fourth and of itself almost equal to vertex width. Pronotum short, arcuate behind, in front much narrowed; propodeum sloping, transversely wrinkled, hairy above. Abdomen with fairly long pedicel, apex and venter with white hairs; mid and hind tibiae with many very short spines, most of them in rows; long spur of hind tibia more than two-fifths of basitarsus. Forewings with marginal cell long, only about one-third its length from wing-tip; second submarginal one-half longer than broad, base curved, receiving the first recurrent beyond the middle; third submarginal much longer and wider behind than the second, about one-fourth narrowed above, receiving the second recurrent (bent near the middle before end of basal third); in hind wings anal ends much beyond the cubital fork.

Phanagenia guerini sp. nov.

♀ Similar in most respects to *Pseudagenia blanda*, but the last tarsal joints have some distinct spines beneath; the third joint of antennae is plainly longer, about equal to the widest part of face; there is a distinct interocellar hump, with an impressed line back of each posterior ocellus; the face is rather narrower above than in typical *P. blanda*, and on the front about one-third way from ocelli to antennae and nearer to median line than to the eyes there is on each side a more or less distinct scar or faint hump. The body is bright metallic blue, the face and clypeus with silvery pubescence, and a large spot of the same on lower mesopleura; the hind femora are reddish; wings clear.

Length 12 to 15 mm.

All the specimens come from the Island of Samar, except one from Surigao, Mindanao.

Phanagenia comes sp. nov.

♀ Black, with silvery pile, densely covering the face, clypeus, posterior border of most of sides of the pronotum, spot on metanotum behind, scutellum, coxae, most of lower mesopleura, and apical part of propodeum, femora and abdomen somewhat sericeous; antennae and legs black; palpi gray; wings faintly infusate, unmarked. A few erect hairs on head and thorax, propodeum short-haired above. Clypeus large, broadly rounded below, almost coming to a point in middle; vertex rather narrow; anterior ocellus a little larger than the others, posteriors not two diameters apart and further from the eyes;

third joint of antennae long and slender, much longer than the fourth, and of itself much longer than the vertex width. Pronotum deeply arcuate behind; propodeum slightly arched, in middle weakly transversely wrinkled, but these fade out on sides; metanotum back of postscutellum rather broad, extremely minutely striate; abdomen with quite long pedicel, the basal segment being narrow for nearly one-half its length, second and third segments large, hairy near tip, and some on venter. Mid and hind tibiae with many short and fine spines, those above are in rows, inner side of hind tibia with a long furrow; long spur of hind tibia about two-fifths of basitarsus. Fore wings with marginal cell not one-half length from wing-tip; second submarginal cell about twice as long as broad, base curved, receiving the first recurrent vein at middle; third submarginal much longer and a little wider behind than the second, receiving the second recurrent (bent in middle) before end of basal third; third abscissa of radius much longer than either the second or fourth which are subequal; in hind wings the anal much before the cubital fork.

Length 13.5 mm.; fore wings 12 mm.

From Sandakan, Borneo.

In appearance it is remarkably close to a species of *Priocnemis* (*P. harpalyce*) in almost every detail, except the lack of teeth on hind tibia and in the shape of the clypeus.

Phanagenia negritos sp. nov.

♀ Black, clothed with a silvery pubescence, dense on clypeus, face, lower mesopleura, coxae, parts of pronotum, end of propodeum, and often on the scutellum. Fore wings almost wholly black, part of base before basal vein clear, and the tip is less dark than middle of wing; hind wings pale, scarcely darker on tips. Face moderately broad, the orbits subparallel; clypeus coming to a point in middle below; a line from antennae to anterior ocellus; ocelli subequal, posteriors nearer to each other than to eyes; vertex back of ocelli elevated from eye to eye, and rounded; third joint of antennae plainly longer than fourth, but not equal vertex width, second plus third however about equal; sparse hair on head, and very short on the propodeum. Pronotum almost angularly emarginate behind; propodeum gently, evenly arched, with very distinct transverse wrinkles; metanotum behind postscutellum with a few striae; abdomen with a short pedicel, the tip and venter hairy. Legs with distinct short black spines on mid and hind tibiae, largely in rows; long spur of hind tibia

not quite one-half of basitarsus. Fore wings with marginal cell about one-half its length from the wing-tip; second submarginal cell scarcely twice as long as broad, its base very plainly curved, receiving the first recurrent vein distinctly beyond the middle; third submarginal very much longer and much wider at tip, receiving the second recurrent (much bent in middle) before end of basal third; third abscissa of radius much longer than second, the second plainly longer than fourth; in hind wings the anal ends before the cubital fork.

Length 13 to 15 mm.; fore wings 12 to 14 mm.

The male is more slender, with more sericeous pubescence, often on the abdomen as well as on head and thorax. On each lower orbit there is a yellowish streak; the front wings are fumose, with a large, darker cloud from marginal cell behind and sometimes a smaller one over basal and transverse. The clypeus is more truncate than in the female; the antennae are long and quite strongly crenulate; the vertex is elevated as in the female; the propodeum is more sloping and indistinctly finely striate; the long spur of hind tibia more than one-half of the basitarsus; the venation very similar to the female.

Length 10-13 mm.

From Mt. Makeling, Mt. Banahao, Los Banos, Luzon; Cuernos Mts., Negros, Island of Samar; Culasi, Panay; Island of Biliran.

PSAMMOCHARINAE.

This subfamily, one of the most specialized, exhibits but little diversity; nearly all of the genera fall in the typical tribe; a few genera go in the Homonotini, and a few more in the Pedinaspini (not yet recorded from the Philippines).

A number of the genera are widely distributed, but each region of the world has a few peculiar genera. A very large proportion of the species are black or almost wholly so.

Synopsis of genera.

1. Antennae situated on upper margin of clypeus; the suprantennal process broad and covering bases of both antennae; clypeus flat, broadly rounded below, hiding the mandibles; head flattened; propodeum ends in a cone-like process each side; pronotum somewhat elongate (*Homonotini*)..... 2
- Antennae situated plainly a little above upper margin of clypeus; suprantennal process narrowed somewhat in front, sometimes absent; clypeus more or less plainly convex, usually very broad..... 3
2. Hind edge of mesopleura pleated; vertex ridge a little rounded... *Platyderes*
Hind edge of mesopleura not pleated; vertex ridge sharp.... *Homonotus*

3. A distinct malar space between eyes and base of mandibles; no tarsal comb. *Paracyphonys*
No distinct malar space. 4
4. Posterior slope of propodeum with a hump each side near the middle or at beginning of slope, sometimes also at tip. 5
Posterior slope of propodeum at most with processes at the lower end. 6
5. Antennae situated in a large shallow pit occupying all of lower face; clypeus narrower than lower face. *Narochares*
No such pits on lower face; suprantennal process very large; last tarsal joint with spines below; female with a tarsal comb. *Tachypompilus*
6. Tip of propodeum extended into a cone-like process each side, concave between. 7
Tip of propodeum not so extended. 8
7. Marginal cell short, more than its length from wing tip. *Aporinellus*
Marginal cell not its length from wing tip. *Ferreola*
8. Front tibiae spined above most of its length; mid tibiae with three spines in the row on lower outer side; last joint of tarsi with spines beneath. *Batazonus*
Front tibiae not or scarcely spined above; mid tibiae with but two (or one) spine on lower outer side. 9
9. Basal abdominal segment with appressed scale-like pubescence, usually also on parts of thorax. *Episyron*
No such appressed scale-like hairs on basal segment of abdomen. 10
10. Front tarsus with a comb of long spines in the female. 11
Front tarsus without distinct comb of long spines. 12
11. Last tarsal joint with spines below. *Psammochares*
Last tarsal joint smooth below. *Sericopompilus*
12. Clypeus elevated at an angle of about twenty-five degrees; antennae short; front tibiae spined only at tip. *Tagalochares*
Clypeus but little elevated. 13
13. Last tarsal joint with spines beneath. 14
Last tarsal joint smooth beneath. 15
14. Propodeum hairy above. *Anoplius*
Propodeum without hairs, or very few on sides. *Pompilinus*
15. Propodeum hairy above; inner tooth of claw sloping, broad, and obliquely truncate. *Anoplinellus*
Propodeum not or scarcely hairy above; inner tooth of claw not obliquely truncate. 16
16. Basal antennal joint longer than the third; no distinct spines at tip of front tibia; mid tibia with two spines on lower outer edge. *Morochares*
Basal antennal joint shorter than third; distinct spines on tip of front tibia, mid tibia usually with but one spine on lower outer edge. *Gymnochares*

BATAZONUS.

Batazonus orientalis Cameron.

Many specimens from Zamboanga, Dapitan, Kidapwan, Kolambugan, Surigao in Mindanao; Baguio Benguet, and Los Banos, Luzon; Island of Sibuyan; and Island of Samar.

It is evident that *Pompilus orientalis* Cam. is the male of *Pompilus bioculatus* Bingh.; in *P. orientalis* the basal joint of the antenna is extremely short as in the males of *Batazonus* in the United States; *P. orientalis* also has the three spines in the row on the lower outer side of the mid tibia as has *B. bioculatus*. *P. orientalis* is remarkable in having scale like appressed hair on basal abdominal segment and in the prominent vertical carina between the antennae from the upper edge of clypeus to above the base of the antennae; the basal joints of the antennae are thus more widely separated than usual.

Pompilus multipictus is described as having this carina, so it is doubtless the male of *Batazonus unifasciatus*.

Batazonus submaculatus sp. nov.

♀ Black, hind femur and abdomen shining bluish, a faint reddish streak each side on face near the emargination of eyes; the post-scutellum reddish, and a transverse spot each side on base of second abdominal segment, almost forming a band; tibiae and tarsi of legs and tips of femora yellowish; wings reddish, extreme tips narrowly dark. Head and pronotum with short, erect hair. Face about as much narrowed above as in *B. bioculatus*; clypeus large, sides rounded, middle nearly truncate below; ocelli large, posteriors hardly as near to eyes as to each other; third joint of antennae longer than vertex width; pronotum angulate behind; propodeum rounded, very hairy; abdomen somewhat depressed, some short hairs above on first segment, longer ones near tip and on venter. Front coxae hairy in front, front tibia spined to base, the three spines on the outer side of basitarsus about their length apart; mid and hind tibiae and tarsi with many rather long, yellowish spines; spurs yellowish; long spur of hind tibia more than half of basitarsus. Venation similar to that of *B. bioculatus*; second and third submarginal cells a little longer than in that species; first recurrent vein ends near tip of second submarginal, second recurrent ends beyond middle of third submarginal.

Length 17 mm.; fore wing 15 mm.

From Dapitan, Kolambugan, Mindanao; Island of Basilan; and Sandakan, Borneo.

TACHYPOMPILUS.

This genus was used by Ashmead for the undescribed species *abbotti*; it was validated by Brown (Philip. Journ. Science I, p. 684, 1906) for his new species *T. ashmeadi*. *Balanoderes* Haupt is, I suppose, to be considered a synonym, but when he described it he says genotype is *P. apicalis* Fabr., but it was evidently intended for *P. analis* Fabr.

Tachypompilus ashmeadi Brown.

This is scarcely distinct from *T. analis* Fabr., but if this widely distributed species is ever split into subspecies, *ashmeadi* can be used for the Philippine form. Specimens come from Iligan, Kolambugan, and Dapitan in Mindanao, and from Lamao, Los Banos, Mt. Makeling, and Mt. Limay in Luzon; Cuernos Mts., Negros; Island of Biliran; and Madrigal, Rizal, Luzon, 30 March (Clagg).

Tachypompilus bakeri sp. nov.

♀ In structure and color closely similar to *T. ashmeadi* Brown (*analis* F.), but the wings are entirely deep violaceous black; abdomen beyond second segment red. At the sides of the propodeum the humps, especially the lower one, are larger than in *T. ashmeadi*, and the lower one is more sharply pointed. The face, clypeus, antennae, and ocelli are as in *T. ashmeadi*; pronotum arcuate behind; abdomen with hairs at base, toward tip, and on venter; pleura and legs as in *T. ashmeadi*, the long spur of hind tibia is a little shorter than in that species, not nearly one-half of the basitarsus, last joint of hind tarsus with spines beneath; long comb on front tarsus as in *T. ashmeadi*; venation as in that species.

Length 14 to 16 mm.; fore wing 13 to 15 mm.

From Mt. Makeling, Luzon; and Surigao, Mindanao.

PARACYPHONYX.

Paracyphonyx pedestris Smith.

From Los Banos, Luzon; Dapitan, Mindanao; Cuernos Mts., Negros; and Tangcolan, Bukidnon.

It is described by Bingham in the Fauna Indica, and very readily recognized by coloration.

EPISYRON.

This readily recognized genus is very well represented in the Philippines, and several of the species appear to be quite common.

The females may be separated as follows:

1. Hind tibia partly reddish. 2
Hind tibia not reddish. 3
2. Clypeus with a yellow spot each side; the marginal cell as long as
the second plus third submarginal cells; spines pale. *vagabundus*
Clypeus unmarked; mid and hind femora also reddish; marginal cell
very short; spines black. *smithi*
3. Clypeus unmarked. 4
Clypeus with pale mark. 5
4. Tarsal comb long; a hump between hind ocelli; first recurrent ends at
middle of second submarginal cell; scales whitish. *pilifrons*
Tarsal comb very short; no distinct hump between ocelli; first
recurrent ends beyond middle of second submarginal cell; scales
bluish. *bakeri*
5. A spot each side on clypeus, not connected; pronotal arc of scales
not very distinct; a spot on hind tibia; spurs whitish; tarsal comb
short. *saussurei*
A yellow mark along lower border of clypeus, sometimes enlarged
at ends; pronotal arc of scales distinct. 6
6. No pale spot on hind tibia; spurs dark; yellow of clypeus does not
reach the sides. *ashmeadi*
A pale spot on base of hind tibia above; spurs white; yellow of
clypeus reaches to the sides. 7
7. Spines of tarsal comb short; face much narrowed above; first recurrent
ends near end of second submarginal cell. *binghami*
Spines of tarsal comb rather long; face less narrowed above; first
recurrent vein ends near the middle of the second submarginal cell.
stantoni

Episyrion bakeri sp. nov.

♀ Black; mostly silvery sericeous, scales on propodeum and basal segment somewhat bluish; clypeus without yellow mark, orbits with a very narrow yellowish band, a spot on hind part of mesonotum, and a yellow dot on each tegula; abdomen with yellow spot each side on base of second and third segment; hind tibia with a short pale streak behind near base. Wings nearly hyaline, tip from beyond middle of marginal cell black; spurs yellow-brown. Clypeus broad, nearly truncate below; ocelli not in a very wide triangle, the posteriors nearer (but not twice) to eyes than to each other; antennae slender, third joint much longer than fourth, second plus third equal vertex width; pronotum deeply arcuate behind; propodeum hairy, evenly rounded; abdomen rather short, hairy at tip; tibiae and tarsi with fairly large black spines, long spur of hind tibia fully three-fourths of the basitarsus; comb on front tarsus of moderately long spines, almost their length apart. Marginal cell about its length from the wing-tip;

second submarginal cell plainly longer than high, receiving the first recurrent vein beyond middle; third submarginal much smaller than the second, much narrowed above, receiving the second recurrent beyond middle.

Length 8.5 mm.; fore wing 7.5 mm.

One from Butuan, Mindanao.

Episyron vagabundus Smith.

Described from Malacca, Celebes; specimens Cuernos Mts., Negros; Puerto Princesa, Palawan; and Sandakan, Borneo; also occurs at Singapore. In general similar to *E. stantoni*, but with reddish hind tibiae; the yellow on clypeus and in orbits broader than in *E. stantoni*. The third submarginal cell (as noted by Smith) is extremely short, while the second is rather longer than usual; the long spur of hind tibia is almost as long as the basitarsus; the spines on tibiae and tarsi of mid and hind legs are pale; in the male, the clypeus has a large pale spot each side, not connected below.

Episyron smithi sp. nov.

♀ Black; clothed with silvery pubescence, the scaly hair on propodeum and basal segment white; the mid and hind femora and tibiae almost wholly reddish, black only at ends. There is no white on head, nor on pronotum, the latter with a whitish sericeous band, and the frontal slope more or less white sheen, no arc of scales; spurs yellow brown; wings slightly fumose, the tips beyond the venation very dark. Clypeus below truncate, ocelli in a rather broad triangle, posteriors almost twice as near eyes as to each other; third joint of antennae a little longer than fourth, second plus third scarcely equal vertex width; posterior margin of pronotum angulate; propodeum smooth, almost truncate behind; abdomen short and convex, second and third segments with a bluish band at base (segments contracted but apparently no spots); tibiae and tarsi with rather large scattered black spines; long spur of hind tibia not quite two-thirds of the basitarsus; no real comb on the front tarsus, spines very short. Marginal cell very short, only about one and one-half as long as broad, triangular, fully twice its length from wing-tip; third submarginal cell short, petiolate, receiving the second recurrent vein at middle; the second submarginal cell much higher than long, receiving the first recurrent beyond middle. The male is very similar but more slender, no marks on head, the antennae ferrugineous, and beyond basal third strongly crenulate; pronotum with a white band behind, apical

part of hind femur and the hind tibia almost wholly red, second, third, and fourth segments with broad bluish gray bands at base, no yellow spots. Wings about the same, but the marginal cell though very short is rather longer than in the female, about twice its width, and the third submarginal is not quite pedicellate, but very much narrowed above.

Length ♀ 9 mm.; fore wing 7.5 mm.

Length ♂ 7 to 8 mm.

From Cuernos Mts., Negros; and Dapitan, Mindanao.

Episyron pilifrons Smith.

♀ Black; face below with silvery pubescence, also on coxae; a pronotal arc of white scales, those on the propodeum, pleura, and first segment somewhat greenish in certain views; second and third abdominal segments each with a large yellow spot each side, an elongate spot on base of hind tibia, band on hind border of pronotum, small spot just in front of scutellum, a dot on wing base, and narrow orbital lines, yellow; no pale on clypeus; spurs pale (but not white), wing tip dark. Face moderately narrowed above; clypeus broadly rounded below; posterior ocelli closer to eyes than to each other, between the posterior ocelli is a swollen area; third joint of antennae longer than the vertex width; comb spines very long, plainly curved; long spur of hind tibia almost three-fourths of the basitarsus. In the fore wing the marginal cell is not its length from wing tip, third submarginal about as high as long, narrowed one-half above; first recurrent ends at middle of second submarginal cell, second recurrent ends beyond middle of third submarginal cell.

Length 10 mm.; fore wing 9.5 mm.

From Iligan, Mindanao and Baguio Benguet, Luzon.

What is probably the male is similar, no mark on clypeus, a spot on hind tibia, orbital lines, hind border of pronotum, dot on base of wings, transverse spot on each side of third abdominal segment, yellow. Last segment white above, wing beyond the cells dark; spurs whitish, dark near tip.

Length 8.5 mm.

From Montalban, Luzon; Cuernos Mts., Negros; and Island of Samar.

Episyron ashmeadi sp. nov.

♀ Black, with much silvery pubescence, scale hairs on propodeum, first segment, arc on pronotum and some on pleura a distinct bluish

or greenish sheen in certain lights, the erect hairs fine and white. Yellow marks as follows: A narrow yellow band along lower margin of clypeus, not reaching the sides, a narrow orbital line, and a fine postorbital line, narrow hind border of the pronotum, a narrow mark near hind margin of mesonotum, a spot on base of each wing (not on tegulae), a small spot each side on second segment, a larger spot each side on third, spots on the fifth segment (usually hidden as are sometimes the others). No spot on the hind tibia; spurs brown to black; front wings beyond the cells dark. Clypeus rounded below, posterior ocelli nearer to eyes than to each other; face plainly narrowed above, tarsal comb of spines of moderate length, only very faintly curved; long spur on hind tibia almost three-fourths of basitarsus; marginal cell scarcely its length from wing tip; second submarginal cell long; third much shorter, fully one-third narrowed above; first recurrent ends near tip of the second submarginal, second recurrent ends beyond middle of the third submarginal.

Length 7 to 11 mm.; fore wing 6.5 to 10 mm.

From Mt. Makeling, Los Banos, Baguio Benguet, all Luzon; Malinao, Tayabas; from Surigao, Butuan, Zamboanga, Kolambugan, all in Mindanao; and Island of Sibuyan.

Male similar, more slender, no spot on the hind tibia, no mark on clypeus, an orbital line, pronotal hind border, and spots on the third segment yellow; spurs dark and wing tips dark; basal segment of abdomen more narrow, so that the abdomen more fusiform than the others.

Length 7 mm.

From Surigao, Butuan, Kolambugan, in Mindanao; from Los Banos and Mt. Makeling in Luzon; Island of Basilan; Island of Sibuyan.

Episyron stantoni Ashmead.

♀ Black; white pubescence on face below, a sheen on legs; the scales of pronotal arc, propodeum, and first segment are pale yellowish, but in certain lights appear greenish. Yellow marks as follows:—clypeal border, narrow in middle but expanded each side to reach the anterior orbital line, which is fairly broad, a post-orbital narrow line, hind border of pronotum, spot in front of scutellum, dot on base of wings, large spot on each side of the second and third abdominal segments, band on base of fifth segment (usually hidden), and an elongate spot near base of the hind tibia; spurs white; wing-tips dark.

Face only moderately narrowed above; clypeus rounded below, almost truncate in middle; posterior ocelli nearer to eyes than to each other, no noticeable swelling between them, the third joint of antennae scarcely as long as vertex width; tarsal comb moderate, the spines scarcely at all curved; long spur of hind tibia fully three-fourths of basitarsus. Marginal cell about length from wing-tip, second submarginal long, third much shorter, more than one-half narrowed above; first recurrent ends at middle of second submarginal cell, second recurrent ends beyond middle of the third submarginal.

Length 7 to 10 mm.; fore wing 6 to 9.5 mm.

From Mt. Makeling, Los Banos, Baguio Benguet, Mt. Limay, all Luzon; and Basilan Island.

The male is more slender; the clypeus with a yellow spot each side, anterior orbits, post-ocular line, hind border of pronotum, spot before scutellum, dot on base of wing, and transverse spot each side on third segment; last segment above white, spot near base of hind tibia pale, spurs white, wing tips beyond cells dark.

Length about 5 to 6 mm.

From Los Banos, Mt. Makeling, and Baguio Benguet, Luzon; Cuernos Mts., Negros; and N. W. Panay.

In some specimens, particularly males, there is a small pale spot on the outer side at tip of front femur and tibia, and sometimes the lower part of the pronotal side lobe is alutaceous.

Episyrion saussurei sp. nov.

♀ Black; not as much silvery as other species, scarcely noticeable on face, but more on pleura, scale hairs of propodeum and first segment whitish, the arc on pronotum not well marked. Yellow spots as follows:—a large spot each side on clypeus, a broad orbital mark, narrow post-orbital line, hind border of pronotum, mark just before the scutellum, dot on base of wings, large spot on second segment, more transverse on third segment, base of fifth, and a spot near base of hind tibia; spurs whitish; tips of fore wings from beyond middle of marginal cell black. Face moderately narrowed above; clypeus nearly truncate in front; ocelli rather large, posteriors nearer to eyes than to each other; third joint of antenna fully as long as vertex width; spines of tarsal comb short; long spur of hind tibia about two-thirds of the basitarsus. Marginal cell its length from wing-tip; second submarginal quite long, third very short, more than one-half narrowed above; first recurrent near middle of the second submarginal

cell, second recurrent ends beyond middle of the third submarginal cell.

Length 9 mm.; fore wing 8.5 mm.

From Mt. Banahao, Prete, Luzon; and Butuan, Mindanao.

Episyrion binghami sp. nov.

♀ Black; face below with dense white pubescence; white sheen on pleura and legs; the scales in arc on pronotum, some on pleura, propodeum, and first segment with a greenish tinge. Yellow spots as follows:—lower border of clypeus, extended up each side, moderately broad orbital line, narrow post-orbital line, spot in front of scutellum, dot on base of wings, large spots on sides of second and third segments of abdomen, and an elongate spot on base of hind tibia; spurs whitish; wings dark from middle of marginal cell out to tip, but extreme tip a little paler. Face much narrowed above, hind ocelli nearly twice as near eyes as to each other; clypeus nearly truncate below; third joint of antennae very long, much longer than vertex width; tarsal comb of short spines, the three on basitarsus about their length apart; long spur of hind tibia about two-thirds of basitarsus; marginal cell about its length from the wing-tip, second submarginal long, third much shorter, narrowed one-half above, first recurrent ends toward end of the second submarginal, second recurrent ends beyond middle of third submarginal.

Length 10 mm.; fore wings 10 mm.

From Calian, Mindanao, Dec. (Clagg coll.) and Iligan, Mindanao.

PSAMMOCHARES.

This genus contains many species in the Temperate regions, but only two in this Philippine material, one of which is widely distributed in India and the Malay region.

Psammochaeres philippinensis sp. nov.

♀ Black, head (except clypeus) and the pronotum and mesonotum red, lower lobe of pronotum much paler, a red spot each side beneath base of forewings; front tibia faintly reddish; spurs dark; wings hyaline, beyond the stigma dark; abdomen and propodeum somewhat sericeous. Face but little narrowed above; clypeus broad, faintly rounded below; ocelli small, posteriors a little nearer to each other than to eyes; third joint of antennae plainly longer than fourth, second plus third not near vertex width, pronotum behind arcuate,

propodeum short, evenly rounded; abdomen short, convex, hairy at tip, scarcely so beneath. Legs of moderate length, smooth; a few spines below on front tibia, tarsal comb of spines scarcely curved; mid and hind tibia with a few scattered spines; long spur of hind tibia half of basitarsus. Wings with short marginal cell, more than its length from the wing-tip, outer side straight; second submarginal cell nearly one-half longer than high; third about as long as high, somewhat narrowed above; first recurrent ends beyond middle of second submarginal, second recurrent ends at middle of third submarginal, this vein somewhat curved outward; basal vein a little before the transverse.

Length 7 mm.; fore wing 6 mm.

From Baguio Benguet, Luzon; Dapitan, Mindanao; and Cuernos Mts., Negros.

Psammochares reflexus Smith.

Specimens from Los Banos, Mt. Makeling, Alabang, Baguio Benguet, and Cuernos Mts., Negros; Culasi, Panay (McGregor).

I think that the *Pompilus bataviae* of Cameron is the same species. It occurs in India, and Bingham has a description.

ANOPLIUS.

The three forms present are separable as below:—

- | | |
|---|----------------|
| 1. Third submarginal cell triangular, or even a little pedicellate..... | <i>valdezi</i> |
| Third submarginal not triangular..... | 2 |
| 2. Fore wing dark only on apical part..... | <i>bakeri</i> |
| Fore wing almost wholly dark..... | <i>tagala</i> |

Anoplius tagala sp. nov.

♂ Black throughout; clypeus and lower face with dense silvery pubescence, also on front and mid coxae, less distinct on mesopleura; fore wings nearly uniform black, rather coppery reflection, somewhat paler near base; hind wings paler on basal half. Body slender; clypeus truncate below; ocelli close together, the posteriors much nearer each other than to the eyes; antennae moderately long, not at all crenulate, second plus third joints not nearly equal to vertex width; pronotum angulate behind, with moderately long hair; propodeum hairy, evenly arched, smooth, no median groove, in certain lights a silvery band is seen near the tip; pleura not hairy; abdomen slender, nearly all segments with short hair above, and longer hair

below, but no very dense brushes below. Tibiae and tarsi with scattered spines, some on hind tibia are as long as the width of the joint; long spur of hind tibia nearly three-fourths of the basitarsus. Marginal cell moderately broad, last abscissa longer than the second, and plainly convex behind; second submarginal cell one-fourth longer than broad, third scarcely longer, much narrowed above; first recurrent ends at apical fourth of the second submarginal cell; second recurrent nearly straight, and ends just beyond the middle of third submarginal; in the hind wings the anal is about interstitial with the cubital fork.

Length 11 mm.

From Mainit River, 6500 ft., Mt. Apo, Mindanao, 27 Oct. (Clagg).

A female from Sandakan, Borneo, with a crushed abdomen may belong to this species; as the head and thorax are very similar, and the fore wing wholly black, and the venation the same, except that the outer side of the marginal cell is straight instead of convex.

Anoplius valdezi sp. nov.

♂ Black; wings fumose, tips darker. Body and basal parts of legs sericeous; vertex, mesonotum, apical part of abdominal segments above, and the venter deep black. Face moderately narrow, but scarcely narrowed above, with a few fine hairs, mostly on vertex; clypeus rounded below; a line from anterior ocellus to the antennae; posterior ocelli nearer to each other than to eyes; antennae short, thick, not crenulate beneath, third plus fourth joints about equal to vertex width; pronotum slightly angulate behind; propodeum low, evenly, but slightly, rounded; abdomen elongate, base broad, without hairs on tip, ventral segments four and five with a dense brush of erect black hair; front coxae with very fine hair in front, front tibia with a few spines beneath; mid and hind tibiae with spines of moderate length, long spur of hind tibia about three-fifths of basitarsus. Wings moderately long; marginal cell scarcely its length from tip of wing, outer side straight; second submarginal cell about as long as high, oblique, third submarginal triangular, almost or quite pedicellate; first recurrent ends beyond middle of second submarginal cell, second recurrent ends at middle of third submarginal, this vein is almost straight; basal vein a trifle before the transverse nervure; in hind wings the anal ends before the cubital fork.

Length 6.5 mm.; fore wing 6.3 mm.

From Island of Basilan.

Anoplius bakeri sp. nov.

♀ Body, legs, and antennae black; wings infuscated, but black near tip; body sericeous, very distinct on clypeus, lower face, parts of pronotum, pleura, propodeum and a very broad band across base of second, third, and fourth abdominal segments above, leaving a narrow apical margin black, the first segment almost wholly sericeous above, the sides black. Quite long hair on upper face, shorter on propodeum and basal segments, long hair at tip of abdomen above and below, and moderately long elsewhere on venter. Face a little narrower above than below, clypeus broad, truncate in front; a very faint line from anterior ocellus to the antennae; posterior ocelli much closer to each other than to eyes; third joint of antennae much longer than the fourth, second plus third about equal to vertex width; pronotum behind angulate; propodeum short, evenly rounded and sloping behind; abdomen moderately short, convex. Front coxae hairy in front, front tibia with two spines below, the basitarsus with a few short, straight spines; mid and hind tibiae with usual spines of moderate length; long spur of hind tibia equal to one-half of basitarsus. Marginal cell about its length from the wing-tip, outer side straight; second submarginal about as long as high, oblique, third scarcely as long, about one-half narrowed above; first recurrent ends much beyond middle of second submarginal cell, second recurrent ends near middle of third submarginal, this vein a little bowed outward; basal vein scarcely before transverse. The last joint of all tarsi and the claw-joint are slightly enlarged.

Length 8 to 9 mm.; fore wing 7 mm.

From Baguio Benguet and Mt. Makeling, Luzon.

ANOPLINELLUS gen. nov.

Very similar to *Anoplius* in that the propodeum is hairy, and no tarsal comb; but the last tarsal joint is smooth beneath; there are two spines on lower outer edge of mid tibia.

This includes *Pompilus clotho* Smith, and a new species from Celebes. *Anoplinellus clotho* Smith

Two from Iligan, Mindanao and Sandakan, Borneo agree with the description of this species from Sumatra.

The head, pronotum, coxae, propodeum and pleura densely long haired, some hairs on the femora, also on the venter and near tip of abdomen; the posterior outer sides of the propodeum have some silvery pubescence. Clypeus truncate; a line from the antennae

to anterior ocellus; ocelli close together, the posteriors, however, not nearer to each other than to the eyes; the antennae slender, the third joint much longer than the fourth and fully equal to vertex width. The propodeum is concave in the middle of the posterior slope. In the fore wings the second and third submarginal cells about of equal length, but the third much narrowed above; the first recurrent ends near the tip of the second submarginal cell; the second recurrent (scarcely curved) ends beyond the middle of the third submarginal cell; a characteristic feature is that the posterior side of the marginal cell is plainly concave behind; in the hind wings the anal vein ends at the cubital fork. The long spur of the hind tibia about two-thirds of basitarsus.

Length 13 mm.; fore wing 13 mm.

POMPILINUS.

Pompilinus nigrifrons sp. nov.

♀ Black throughout, except wings infuscated and black beyond the cells; clypeus sericeous, hardly so elsewhere. Face rather narrow, scarcely narrowed above, upper face with some rather long hairs; clypeus nearly truncate below; a line from anterior ocellus to antennae, posterior ocelli nearer to each other than to eyes; third joint of antennae longer than the fourth, second plus third equal to vertex width; pronotum angulate behind; propodeum short, evenly arched and sloping behind; abdomen short, convex, with fine hairs at tip, very few on the venter. Front coxae hairy in front, front tibia with a few spines below, outer spines on the basitarsus are short and straight; mid and hind tibiae with scattered, fairly long spines, these femora with a few minute spines near tip above; long spur of the hind tibia one-half of the basitarsus. Wings moderately long; marginal cell much more than length from wing-tip, the outer side straight; second submarginal cell about as long as high, oblique; third submarginal fairly long below, above almost or quite pedicellate; first recurrent vein ends beyond middle of second submarginal, second recurrent ends about at middle or a little beyond in the third submarginal, this vein is scarcely bowed outward; basal vein a little before the transverse.

Length 7 to 7.5 mm.; fore wing 6.5 mm.

From Baguio Benguet, Mt. Makeling, Luzon; and Surigao, Mindanao.

SERICOPOMPILUS.

Sericopompilus bivittatus sp. nov.

♀ Black; clothed with a white pubescence, most prominent on clypeus, lower face, occiput, posterior border of pronotum, a stripe on each side of mesonotum extending past the scutellum; the propodeum, pleura, and bands on apical three-fourths of abdominal segment not as densely sericeous, leaving the bases deep black, the basal segment almost wholly sericeous, except on sides; legs and venter mostly sericeous; spurs whitish; wings almost hyaline, beyond cells black. Face somewhat narrowed above; clypeus broad, slightly rounded below; a line from anterior ocellus to antennae; ocelli moderately large, posteriors nearer to each other than to eyes; vertex with a few hairs; pronotum arcuate behind; propodeum low, gently arched, a faint median line; abdomen moderately long, depressed on basal part, fine hairs at tip; front coxae scarcely hairy in front, front tibia with a few spines below, tarsal comb of long spines, slightly curved; mid and hind tibia with the usual spines moderately long, long spur of hind tibia fully two-thirds of basitarsus. Wings moderately long; marginal cell short and broad, much more than its length from the wing-tip, outer side straight; second submarginal cell one-half longer than high, narrowed above, third submarginal not nearly as long as the second, narrowed one-half above; both recurrent veins end a little beyond the middle of the cells, second recurrent sinuous; basal vein interstitial with the transverse; in hind wing the anal ends before the cubital fork.

Length 9 mm.; fore wing 7.5 mm.

From Iligan, Mindanao; and Cuernos Mts., Negros.

Sericopompilus canifrons Smith.

One from Sandakan, Borneo; not uncommon at Singapore.

TAGALOCHARES gen. nov.

The anterior lobes of pronotum do not bulge out, but about even with the rest of sides, which are parallel. The last segment of abdomen has stiff bristles above; the last joint of hind tarsus is smooth beneath; the propodeum is rounded, with fine, short, erect hair above; no tarsal comb; front tibia with only one or two spines near tip; third joint of antennae long; marginal cell rather long, pointed, not near its length from tip of wing; second and third submarginal moderately

long, the transverse is plainly a little before the basal vein; in hind wing the cubital fork is a little beyond end of anal cell; claw with tooth near middle; maxillary palpi with second joint longest. Differs from all other forms in the clypeus; this is broad, and elevated at an angle of about thirty degrees from the face; the lower margin is double, the margin is a fine ridge, a little before it is a very plain subterminal ridge, between the two the space is concave. Except for the clypeus and stiff bristles at tip of abdomen it is related to *Sericopompilus*.

Tagalochares plutonis sp. nov.

♀ Deep black throughout, wings violaceous, abdomen faintly so. Face narrow, orbits subparallel; clypeus slightly concave in middle below; a line from anterior ocellus to the antennae; ocelli large, close together, but posteriors are fully as near to eyes as to each other; antennae moderately long, third joint nearly twice as long as fourth; second plus third equal the vertex width; pronotum short, arcuate behind; scutellum very convex; propodeum short, nearly evenly rounded, behind the slope is somewhat transversely flattened, plainly silvery, above with numerous fine erect hairs. Abdomen rather long, convex, bristles at tip, and hairs on venter. Legs of moderate length, hind tarsi very long; front legs with few spines, three on outer side of basitarsus, front coxae hairy in front; mid and hind tibiae and tarsi with moderately long spines, not very numerous on tibia, long spur of hind tibia about two-fifths of basitarsus, the tarsal joints (except fourth) elongate. Marginal cell with outer side nearly straight; second submarginal one-half longer than high, base curved; third submarginal about as long as second, narrowed one-half above; first recurrent ends near tip of the second submarginal, second recurrent ends near middle of third submarginal, this vein is much bowed out in middle.

Length 14 mm.; fore wing 12 mm.

From Surigao, Davao, and Iligan, all in Mindanao.

MOROCHARES gen. nov.

In many ways similar to *Sericopompilus*; the anterior part of pronotum scarcely bulging as much; last joint of hind tarsus smooth beneath; front legs with few spines, two on lower outer edge of tibia, no comb, basitarsus equal next three joints, the second joint plainly shorter than fifth; claws cleft, inner part broad, and oblique at tip; propodeum short, rounded behind; hind femora rather short; third

joint of antennae not much longer than fourth; marginal cell not its length from wing-tip, pointed; second and third submarginal cells subequal; basal vein interstitial with transverse; in hind wing the cubital fork is a little beyond end of anal cell; hairs at tip of abdomen fine. Maxillary palpi with all joints moderately short and subequal. Differs from *Sericopompilus* in less spinose front legs, and in the claws. Possibly related to *Anospilus*, which has a longer propodeum and a strong tarsal comb.

Morochares fascipennis sp. nov.

♀ Black; sericeous over most of body and legs, most noticeable on lower face, sides of pronotum, hind part of propodeum, and on the basal parts of the abdominal segments, the apical half of all but the last are not sericeous, but jet black. Wings hyaline, a cloud over basal vein and elongated over the transverse, a broad dark band behind marginal cell across wings, beyond the wing is whitened to the tip; hind wings slightly dark at tip. Clypeus broad, truncate in front; line above base of antennae half way up; ocelli rather large, posteriors much nearer to eyes than to each other; vertex with extremely fine hair, third joint of antennae plainly longer than the fourth, second plus third almost equal vertex width; pronotum moderately long, angulate behind; propodeum not very long, low, scarcely arched on basal part, apex sloping, trace of a median line; abdomen moderately convex, hairy at tip and on venter; legs of moderate length, front pair with short tarsal joints, almost no spines; mid and hind tibiae and tarsi with rather short spines; long spur of hind tibia not one-half of basitarsus. Marginal cell long, outer side convex; second submarginal cell one-fourth longer than high, base curved; third submarginal shorter, but narrowed only a little above; first recurrent vein ends a little beyond middle of second submarginal cell, second recurrent ends near middle of third submarginal, this vein curving outward.

Length 11 mm.; fore wing 8 mm.

From Los Banos; Mt. Makeling in Luzon; and Island of Samar.

GYMNOCHARES.

Several of the small Philippine species seem to agree fairly well with this American genus, and I place them there for the present.

- | | |
|---|---|
| 1. Pronotum marked with pale; hind tibia with pale streak above | 2 |
| Pronotum wholly dark | 4 |

2. Clypeus with pale spots, also on mandibles; no cloud in fore wing.
maculalis
 Clypeus unspotted..... 3
 3. A pale line in middle orbits..... *orbitalis*
 No pale in orbits..... *tibialis*
 4. Spurs white; second plus third antennal joints not equal to vertex
 width..... *pulchella*
 Spurs brownish; second plus third antennal joints about equal
 vertex width..... *persimilis*

Gymnochares persimilis sp. nov.

♀ Black; similar to *G. pulchellus* in markings, but dark bands on wings darker, and the broad one filling out the marginal cell; spurs brown; body not nearly as sericeous as *G. pulchellus*. In structure also similar; clypeus truncate below; face much more narrow above than in *G. pulchellus*; the third antennal joint a little longer than in that species, so that the second plus third fully equal the vertex width; a faint line from anterior ocellus to antennae, post ocelli plainly nearer to eyes than to each other, propodeum more plainly arched than in *G. pulchellus*. Legs spined as in that species, but the long spur of hind tibia is scarcely one-half of basitarsus; the hind femora are a little longer than in that species; venation about the same.

Length 8 mm.; fore wing 7.5 mm.

From Butuan and Surigao in Mindanao.

Gymnochares pulchellus sp. nov.

♀ Black; almost wholly clothed in a sericeous pubescence, at least in certain lights; tips of abdominal segments dark; spurs white; wings hyaline, a dark band over the basal and transverse veins, a broad dark band across wing behind stigma, leaving the extreme tip of marginal cell pale. Face rather broad; clypeus broad, truncate in front; a line from anterior ocellus to the antennae, post ocelli a little nearer to eyes than to each other; antennae moderately long, the third joint scarcely longer than the first, but second plus third not nearly equal to vertex width; pronotum moderately long, wholly sloping forward, hind border arcuate; propodeum low, only slightly arched, and a little narrowed toward tip; abdomen rather short, broad, and convex, near the tip with fine hairs above and below; legs fairly short, especially the front pair, the hind femur not reaching to tip of abdomen; front tibia with about three spines on outer lower edge; mid and

hind tibiae and tarsi with many spines, none as long as thickness of joint, hind femora with a few minute spines near tip; long spur of hind tibia more than one-half of basitarsus. Wings moderately long; the marginal cell not its length from wing-tip, outer side straight; second submarginal scarcely longer than high, third longer than second, very much narrowed above; first recurrent ends beyond middle of second submarginal, second recurrent ends at about middle of third submarginal, this vein curves in the middle.

Length 7.5 mm.; fore wing 6.5 mm.

From Los Banos, Mt. Makeling, Mt. Banahao, Luzon; Surigao, Davao, Iligan, Dapitan, Zamboanga, Kolambugan, Butuan, Mindanao; Isle of Basilan; Island of Samar; and Sandakan, Borneo. It is evidently related to *Pompilus properans* Cam. from southern Borneo, but there are several points in the venation of that species which do not fit this one.

Gymnochares maculalis sp. nov.

♀ Black, a white spot on each mandible and one on each side of clypeus, a white line in each orbit, hind border of pronotum white, spurs whitish, no distinct mark on fore wings, legs brownish to yellowish beyond the base (may not be fully colored). Clypeus very broad, truncate below; face plainly narrowed above; posterior ocelli much nearer to the eyes than to each other; third joint of antennae longer than fourth, second plus third equal vertex width; pronotum deeply arcuate behind; the propodeum sloping, a few hairs above; mid and hind tibiae with short spines above; long spur of the hind tibia about three-fifths of the basitarsus. In fore wing the marginal cell is long, about one-half its length from wing-tip; second submarginal cell almost twice as long as broad, receiving the first recurrent vein at apical third; third submarginal very much shorter, and one-half narrowed above, receiving the second recurrent near middle; third abscissa of radius about one half of second, second plus third about equal to fourth; in hind wing the anal ends much before the cubital fork.

Length 7 mm.; fore wing 6.5 mm.

From Dapitan, Mindanao; one specimen.

Gymnochares orbitalis sp. nov.

♂ Black, a narrow yellow line on inner orbits, most of posterior part of pronotum yellowish, tegulae pale yellow; scape beneath

yellowish, a pale yellowish spot on base of hind tibia, extreme tips of front femora pale reddish; spurs dark; wings hyaline, with the tip beyond the stigma mostly dark. Face moderately wide, not narrowed above; clypeus nearly truncate below; ocelli in a low triangle, posteriors small, a little nearer to eyes than to each other; antennae short and very heavy, not crenulate, third plus fourth joints not equal to vertex width; pronotum behind deeply arcuate; propodeum sloping, scarcely arched, silvery pubescent; abdomen elongate, compressed behind, last segment white above, no hairs; front tibiae without distinct spines below; mid and hind tibiae with short spines above, long spur of hind tibia about two-thirds of basitarsus. Wings with marginal cell nearly its length from wing-tip, outer side scarcely convex; second submarginal longer than high, third not as long as the second, somewhat narrowed above; first recurrent ends beyond middle of second submarginal cell, second recurrent ends at middle of third submarginal, this vein a little bowed outward; basal vein just before the transverse; in hind wings the anal interstitial with the cubital fork.

Length 5 to 6 mm.; fore wing 4.5 to 5.5 mm.

From Tacloban, Leyte, and Baguio Benguet in Luzon.

Gymnochara tibialis sp. nov.

♀ Black, covered with a fine white pubescence; hind border of pronotum yellow; spurs whitish, darker on tips; hind tibia with a pale spot near base; wings hyaline, a broad dark band from marginal cell nearly across the wing, a narrow band over the basal veins (sometimes faint). Face very broad, but little narrowed above; clypeus broad, truncate below; ocelli in a low triangle, posteriors almost as near to eyes as to each other; third joint of antennae longer than the first, second plus third almost equal to vertex width. Pronotum short, subangulate behind; propodeum long, but little arched; abdomen short, rather broad, convex, tip with fine hairs; legs moderately short, mid and hind tibiae and tarsi with numerous short spines, a few minute ones on these femora toward tip; front tibia with a few on outer lower edge; long spur of hind tibia about two-thirds of the basitarsus. Marginal cell not its length from wing-tip, outer edge nearly straight; second submarginal cell scarcely longer than high, third submarginal a little longer below, somewhat narrowed above, both recurrent veins end beyond middle of cells, second recurrent but little curved.

Length 6 to 8 mm.; fore wing 5 to 7 mm.

Male much more slender, antennae only slightly undulate beneath, band on pronotum and spot on hind tibia as in female; wings marked the same, long spur of hind tibia about three-fourths of basitarsus.

From Mt. Banahao, Baguio Benguet, Luzon; Surigao and Dapitan in Mindanao, Malinao, Tayabas; Cuernos Mts., Negros; and Island of Samar.

NAROCHARES gen. nov.

The face has a large elongate depression on each side from which arise the antennae, thus reminding one of *Clavelia*. However the tibiae have scattered spines, the femora have a spine at tip, and hind femora a few minute ones before tip, the tips of mid and hind tibiae have divergent and very unequal spines, the last joint of tarsi smooth beneath, there is a distinct pocket in base of the second discoidal cell, the pronotal side lobes are broad below, so it must belong to the *Psammocharinae* although the reborder to the end of propodeum is quite small. The occiput is concave; the face is narrow, and much narrower at vertex than at clypeus, the clypeus transverse, the sides not sloping, the lower margin truncate, no sign of planation (as in *Pedinaspis*), the pronotum is scarcely longer than usual in many *Psammocharinae*, but in front is vertical with almost a ridge above (reminding one of *Xanthampulex*) and at the middle with two flat teeth, the claws are cleft; the propodeum has a distinct corner or tooth each side at the beginning of the posterior slope. The venation is similar to many of the *Psammocharinae*, three submarginal cells, moderately large pocket in the second discoidal, the basal interstitial with the transverse nervure. It has much the appearance of and, I presume, most affinity with *Gymnocharaxes*.

Narocharaxes clavelina sp. nov.

♂ Black, with a bluish metallic iridescence in many parts; the wings hyaline, fore wings with two black bands, one over the basals, broad behind; a much broader one from marginal cell back across; hind wings with dark tip. Face about one half as wide at vertex as at clypeus; a large pit each side, fading off above into the front; clypeus truncate below; a faint line from antennae to anterior ocellus; ocelli subequal, rather close together, posteriors much nearer to eyes than to each other; antennae slender, third joint barely longer than fourth, second and third more than equal vertex width; no erect hair on head nor thorax; pronotum deeply arcuate behind, the definite

front margin with two rather broad teeth near the middle; propodeum short, rounded, at beginning of the posterior slope each lateral angle is formed into a small tooth, posterior slope silvery. Abdomen rather short, convex, a few hairs near tip and on venter; legs with front tibia with a few spines toward outer tip, and a few very fine ones below; mid and hind tibiae with scattered, moderately long spines; long spur of the hind tibia fully one-half of the basitarsus. Marginal cell rather long, pointed at tip, about one-half its length from the wing-tip; second submarginal cell a little longer than broad, receiving the first recurrent vein at middle, the veinlet separating it from the third submarginal not as heavy nor as distinct as the other veins; third submarginal longer than the second, about one-third narrowed above, receiving the second recurrent (which is outcurved) beyond the middle; in hind wings the anal ends much before the cubital fork.

Length 8.5 mm.; fore wing 7.5 mm.

From Island of Samar, one female.

FERREOLA.

This name has often been sunk under *Pedinaspis*; I am using it for species which have an elongate pronotum, and the propodeum is produced behind in two tubercles. It appears to be a natural group, but perhaps should have another name.

The three species are tabulated as follows:

- | | |
|--|------------------|
| 1. Body plainly bluish..... | <i>violacea</i> |
| Body black..... | 2 |
| 2. Abdomen with sericeous bands; clypeus partly white..... | <i>clypealis</i> |
| Abdomen without bands; clypeus wholly dark..... | <i>tagalica</i> |

Ferreola clypealis sp. nov.

♂ Black; clypeus white with a median black spot, wholly silvery; face with dense white pubescence; thorax almost wholly silvery sericeous, leaving black median area on the notum; legs also silvery; abdomen black, with first segment wholly white pubescent above, the second and third with a broad apical white pubescent band; venter almost wholly white pubescent; wings from the basal vein out are black. Clypeus rounded below; ocelli subequal, a hump between the posteriors, these much nearer eyes than to each other; antennae short and thick; pronotum arcuate behind; propodeum smooth, extended behind each side as usual; abdomen with hairs near tip and on venter;

legs with stout black spines on tibiae and tarsi; long spur of hind tibia nearly two-thirds of basitarsus. Marginal cell moderately long, pointed, its outer side long and somewhat concave behind; the second submarginal cell a little longer than high, receiving the first recurrent vein at apical third; the third submarginal fully as large as the second, very roundedly narrowed above to almost a point, and receiving the second recurrent at middle.

Length 8 to 13 mm.; wing 7 to 11 mm.

From Island of Sibuyan; Butuan, Davao, Mindanao.

In appearance almost exactly like *F. bakeri* from Singapore; however, the white clypeus, the larger amount of black on the wing, the marginal cell concave behind, the longer third submarginal cell, and basal segment wholly white above separate it from that species.

Ferreola violacea sp. nov.

♀ Black, head with some greenish or bluish reflection; thorax, abdomen, and basal parts of legs violaceous to deep blue; wings violaceous black. Head with short hairs; clypeus slightly concave in front; ocelli in a low triangle; post ocelli plainly nearer to eyes than to each other; antennae short, third joint not as long as first, and not longer than fourth; pronotum long, fully as long as mesonotum, from above the sides are plainly concave, hind border subangulate; scutellum broad, flat; propodeum long, sloping, very hairy, at apical third rather suddenly narrowed each side, the slope deeply excavate, the sides projecting as rounded lobes; abdomen elongate, convex, several segments near tip, base of basal segment, and venter with fine, erect hairs, elsewhere scarcely noticeable. Legs smooth, front pair short, basitarsus equal three joints, with very few spines, front coxae hairy; mid and hind tibiae and tarsi with rather short spines; claws cleft; long spur of hind tibia about one-half of basitarsus. Wings long; marginal cell not its length from wing-tip; second submarginal nearly one-half longer than high, both ends curved; third submarginal a little longer, but much narrowed above; first recurrent ends near end of the second submarginal, second recurrent ends a little before middle of third; basal and transverse interstitial; radial vein arises before the middle of stigma; in hind wing the anal cell is angulate below where the evanescent vein crosses.

Length 18 mm.; fore wing 17 mm.

From Calian, Davao Province, Mindanao, Dec. (Clagg coll.), also Butuan; Cuernos Mts., Negros; and N. W. Panay.

Ferreola tagalica sp. nov.

♀ Black, somewhat violaceous in certain lights; wings deep black. Clypeus almost truncate below; a line from anterior ocellus to the antennae; ocelli in an equilateral triangle, posteriors hardly as far from eyes as from each other; antennae short; third joint no longer than fourth, and hardly equal to first; pronotum rather short, plainly shorter than mesonotum, arcuate behind, from above slightly indented each side; scutellum nearly flat, but more tapering than in *F. violacea*; propodeum moderately long, deeply excavate behind, sides prolonged behind into a sharp tooth, a faint median line on basal part; abdomen elongate, convex, hairy on venter and last dorsal segment. Front legs rather short, with very few spines, a few on tibia and very weak ones on tarsus, basitarsus about equal to next three joints; mid and hind tibiae and tarsi with spines fairly long; last joint of hind tarsus smooth beneath; long spur of hind tibia more than one-half of basitarsus. Marginal cell less than length from wing-tip, its outer side faintly concave behind (fourth abscissa); second submarginal a little longer than high, base curved, third no longer and more than one-half narrowed above; first recurrent ends near end of the second submarginal cell, second recurrent ends near middle of third submarginal; radial vein arising a trifle before middle of stigma; in hind wing the anal cell is a little curved, but not angulate at evanescent vein.

Length 16 mm.; fore wing 15 mm.

From Calian, Davao Province, Mindanao, Dec. 5500 ft. (Clagg coll.), also Iligan, Butuan, Davao, and Kolambagan.

APORINELLUS.

Aporinellus bakeri sp. nov.

♀ Black, with a silvery pubescence on clypeus and lower part of face, on the pronotum (leaving a black band before tip) on mesonotum, propodeum, most of the pleura, basal parts of legs, most of the basal segment of abdomen, and broad, apical bands on the following ones; wings hyaline, front pair broadly black-tipped, hind pair darkened on tip. Face broad, nearly as broad as high; clypeus very broad, in middle below a little concave; line on face from antennae to anterior ocellus; posterior ocelli a trifle nearer to eyes than to each other; antennae short, third joint plainly longer than the first or fourth; pronotum arcuate behind; main part of propodeum nearly flat, apex each side prolonged into a tooth; abdomen short, convex, a few hairs

near tip and on venter; legs rather short; comb on front legs of moderately long spines, some slightly curved; mid and hind tibiae and tarsi with numerous rather long spines; long spur of hind tibia nearly three-fourths of the basitarsus. Marginal cell sub-triangular, outer side straight; second submarginal cell not longer than high, base curved; third scarcely longer and very much narrowed above; first recurrent ends before middle of the second submarginal cell, second recurrent ends beyond middle of the third submarginal, this vein scarcely curved; transverse nervure is a little before the basal.

Length 6 mm.; fore wing 5 mm.

From Los Banos, and Mt. Banahao in Luzon, and Taclobar, Leyte; Manila (C. S. Banks); Cuernos Mts., Negros.

♂ Black, last segment of abdomen white above, spurs black, fore wings faintly infusate, the tips darker, hind wings hyaline. Clothed with silvery pubescence, on hind margin of pronotum forming a distinct band; on abdomen the first segment is wholly and the next three with an apical broad band of silvery, tarsi and antennae dull black. Clypeus truncate below, ocelli in low triangle, posterior hardly twice as near to eyes as to each other; pronotum arcuate behind; propodeum nearly flat, but at tip excavated, the corners somewhat produced; abdomen slender, somewhat depressed, hardly any hairs at tip; legs with a few spines on front tibia near tip, mid and hind tibiae and tarsi with many short spines and a few on upper tips of these femora, long spur of hind tibia almost equal to the basitarsus. Marginal cell of fore wings more than its length from wing tip; second and third submarginals small, subequal, first recurrent ends just before middle of second submarginal, second recurrent ends much beyond middle of the third submarginal, basal vein interstitial with transverse.

Length 5 mm.; fore wing 4 mm.

From Manila, Luzon (C. S. Banks).

Haupt puts *Aporinellus* as a synonym of *Pompiloides*; however, Ashmead fixed the type of *Pompiloides* as *unicolor*, and this species Haupt (1929) has placed in *Anoplius*, so *Pompiloides* is a synonym of *Anoplius*, and *Aporinellus* is to be used for the *Pompiloides* of Haupt.

PLATYDERES.

This genus contains species in India and Australia which are extremely similar in appearance to the Philippine forms.

The three forms are separated below:

- | | |
|--|----------------|
| 1. Only the pronotum reddish | 2 |
| Pronotum, part of mesonotum and the mesopleura reddish | <i>extensa</i> |
| 2. Inner orbits with a pale line | <i>excepta</i> |
| Inner orbits without pale line | <i>partita</i> |

Platyderes partita sp. nov.

♂ Black; the pronotum reddish, tegulae paler, palpi pale, except base; wings hyaline on basal part, from just before basal vein very dark; hind wings dark on tip. Body with fine white pubescence, most noticeable on lower part of face, on pleura, coxae, femora, and tibiae, and usually a prominent band across the bases of the first and second abdominal segments above; the last few segments (or all of them) show a reddish brown pubescence. The vertex is plainly rounded; the ocelli in a low triangle, the posteriors much further apart than from eyes, but not twice as far; clypeus evenly rounded below; the pronotum very long, its hind margin slightly but distinctly bisinuate; propodeum long, its upper side slightly convex, deeply excavate behind, the sides prolonged backward, within the base of this excavation are several distinct longitudinal ridges, from above the pronotum is distinctly concave on the sides. Abdomen depressed on basal part, on venter near tip are a few short hairs. Hind and mid tibiae and tarsi with numerous short spines, a few at tips of these femora, last joint of hind tarsus smooth beneath, long spur of hind tibia about two-thirds of basitarsus, claws cleft. In fore wings the basal vein interstitial with the transverse; marginal cell long and sharp tipped, second submarginal longer than broad, base rounded, apex straight; third submarginal still longer and much narrowed above; first recurrent ends just before middle of the second submarginal, second recurrent ends at middle of third submarginal.

Length 9 mm.; fore wing 7 mm.

From Los Banos, Mt. Makeling, Alabang, Luzon; Island of Samar; and Sandakan, Borneo.

The female is similar, but larger (12 to 15 mm.). The colors the same; the pronotum is rather longer, very distinctly constricted in middle (seen from above). The spines on the mid and hind tibiae are more numerous than in the male, on the hind tibia above the spines occupy almost the entire posterior surface, so densely are they placed; the posterior concavity of the propodeum has the same longitudinal ridges as in the male.

Platyderes partita var. *excepta* var. nov., the male from Los Banos differs in several ways and may indicate a separate species when the

female is known. The general colors are the same, the orbits, however, have a distinct yellow line, and a very fine pale line back of the eyes; the abdomen is rather broader and flatter than usual, and of an entire purplish color; the most characteristic difference is that the concavity of the propodeum is more sharply defined above and there are no longitudinal ridges; the venation is the same; the black of fore wings extends considerably beyond the basals.

Platyderes extensa sp. nov.

♂ Extremely similar to *P. partita*, the red of the pronotum extends over most of the mesonotum and upper part of mesopleura, the tegulae are white, the white pubescent bands on first and second segments of the abdomen are a little broader. In the fore wing the marginal cell is a little shorter, the second submarginal as in *P. partita*, the third is a little shorter, not longer than second, and much narrowed above; the first recurrent ends before the middle of the second submarginal, and the second recurrent ends much beyond middle of third submarginal. The fore wing has much more hyaline or almost hyaline, the dark only out from before marginal cell, and around base of the second discoidal, leaving a pale area in the middle out to beyond the third submarginal cell; hind tibia not as densely spined as in *P. partita*, only about two rows.

Length 7 to 9 mm.; fore wing 6 to 8 mm.

From Puerto Princesa, Palawan; and Mt. Makeling, Luzon.

These two species are similar to *P. cameroni* and *P. circe* (= *fulvicollis* Guer.) of India, but there are several points in their descriptions that do not fit these species; the Australian *P. collaris* is also closely related.

HOMONOTUS

This is probably the most highly developed of the family, as is shown in the flattened head, the very concave occiput, elongate pronotum; propodeum with angles prolonged behind. The number of submarginal cells varies in the species, some having but two.

The three species from the Philippines separate as below:

1. Fore wings with the second and third submarginal cells united; tibiae more or less rufous..... *rufipes*
Fore wings with second and third submarginal cells separate; tibiae black..... 2
2. A cloud in fore wing just beyond the stigma; no stub to base of the first submarginal cell..... *nebulosus*
No cloud in fore wing; a distinct stub of a vein on the basal side of the base of the first submarginal cell..... *tagalicus*

Homonotus tagalicus sp. nov.

♀ Black; body, coxae, and femora almost wholly covered with sericeous pubescence, on some abdominal segments it is less dense in the middle, the upper part of face and the base of pronotum less sericeous; spurs white; palpi yellowish; wings faintly fumose, hind wings hyaline. Face narrowed above; ocelli in a low triangle, posteriors about twice as near to eyes as to each other; clypeus broadly rounded below; antennae short, third joint about equal to the fourth, or a little shorter; pronotum arcuate behind; propodeum long, posterior angles fairly sharp; front legs almost devoid of spines, a very few near tip of femur and tibia, the tarsi with microscopic spines; mid and hind tibiae and tarsi with numerous rather short spines, and a few on these femora toward tip; long spur of hind tibia not reaching to tip of the basitarsus. In fore wing the marginal cell is not its length from the wing tip; the second and third submarginal cells subequal in length, both a little longer than high, first recurrent vein ends before middle of second submarginal, second recurrent ends beyond middle of third submarginal, in all specimens the base of the first submarginal shows a more or less distinct stub of a vein projecting basally from its middle.

The male is similar, with a much more slender body, the long spur of hind tibia equals the basitarsus.

Length ♀ 8 to 11 mm.; fore wing 7 to 9.5 mm., ♂ length about 6 mm.

Specimens from Mt. Makeling, Los Banos, Baguio Benguet, Mt. Banahao, in Luzon; Dapitan, Davao in Mindanao; and P. Princessa, Palawan.

Extremely close to *Pompilus ariadne* Cam., which, I suppose, is a *Homonotus*. Female specimens from Singapore and Hongkong agree with *P. ariadne* in having the long spur equal to the basitarsus; the pronotum in these is a little shorter than in *H. tagalicus*. In the females that are largest the crest of vertex is higher than in others (var. *alticeps*), often the distance from crest to a posterior ocellus is greater than the distance from a posterior to the anterior ocellus; but this point varies a little.

Homonotus rufipes sp. nov.

♀ Black, polished, body and upper parts of legs with some sericeous pubescence particularly at the tip of the propodeum, and on the base of several abdominal segments; lower margin of clypeus reddish; antennae (especially basal part) reddish brown; tibiae and tarsi

reddish; spurs white; wings slightly fumose, darker toward tip. Clypeus rounded below; ocelli small, subequal, the posteriors three times as near to eyes as to each other, and only a little below the vertex ridge; antennae short, third joint but little longer than the fourth, second plus third plus fourth scarcely more than the vertex width; pronotum nearly transverse behind; propodeum long, with the usual processes behind; abdomen slender, a few very short fine hairs near tip of venter; legs short, spines black, fairly stout; hind tibia with two rows above and some on the sides; long spur of hind tibia four-fifths of the basitarsus. Marginal cell fairly long, pointed behind, but two submarginals, the second and third, being united, making a cell about two and a half times as long as high, the first recurrent ends near the base, and the second recurrent ends a little before the tip of this cell.

Length 6 mm.; fore wing 4 mm.

The male is similar, but smaller, the antennae thicker, but the body is scarcely more slender, the abdomen is tipped by two small points. Length 4 mm.

From Los Banos, Mt. Makeling, Luzon; Cuernos Mts., Negros; and Kolambagan, Mindanao.

Homonotus nebulosus sp. nov.

In general very similar to *H. tagalicus*. The third submarginal separate, the second rather longer below than third; fourth abscissa of radius fully as long as third; second recurrent received in middle of third submarginal cell (instead of much beyond in *tagalicus*). There is a distinct dark cloud in the fore wing over the marginal, second and third submarginals, and a little into the second discoidal cell. The vertex, seen from in front is somewhat truncate across top (not evenly rounded as in *tagalicus*); there is no stub to the base of the first submarginal cell. Otherwise very like that species; spurs white, the long one as long as the basitarsus; crest of vertex not especially high; the anterior ocellus almost as close to middle of vertex as to the posterior ocelli; latter more than twice as near eyes as to each other.

Length 5 mm.

From Puerto Princesa, Palawan.

NOTOCYPHINAE.

This subfamily has previously not been reported from the Old World. Two species are present belonging to a new genus which is

extremely remarkable in having small spines situated in pits on the underside of the femora. I have found a Brazilian species with the same character.

MINOTOCYPHUS gen. nov.

Belongs to the Notocyphinae; the labrum wholly extended, broader than long, and rounded below; face narrow, scarcely if at all widened above; eyes not emarginate within, below they do not quite reach to the mandibles, leaving a distinct malar space; stigma on propodeum near middle; no distinct reborder to the propodeum at tip, the outer angles prolonged into sharp lobes; legs with only very minute spines on the tibiae of mid and hind legs and on the under surface of these femora, all scarcely projecting out of their pits; the tip of the mid and hind tibiae and also the tip of these basitarsi have a row of very small subequal parallel spines (like those of *Notocyphus*); claws cleft. Eyes of female minutely hairy; head scarcely extending back of the eyes; pronotum moderately long, the lower sides in a broad lobe; abdomen compressed toward tip; wings with venation much like *Notocyphus* except that the base of second submarginal cell is not or scarcely oblique. It differs from *Notocyphus* in the broader labrum; in having the hind corners of propodeum prolonged into lobes; in the less oblique base of second submarginal cell. Not only the extruded labrum but the spines at tips of tibiae and basitarsi place it in the *Notocyphinae*. The presence of minute spines on the under surface of the mid and hind femora is not found in most other species of the group (or indeed of the family); however in one handsome South American species of *Notocyphus* there are the same small spines from pits on the under surface of the mid and hind femora.

Type *M. obesus* n. sp.

Minotocyphus obesus sp. nov.

♀ Brownish black; head with a yellow stripe by each inner orbit, and a narrow yellow line back of the eyes; clypeus with a large whitish spot each side connected along the lower border; lower sides of pronotum alutaceous near tip; femora and tibiae almost wholly reddish, the tarsi brown; on propodeum the apical lobes are mostly whitish, and there is a yellow spot on the postscutellum, and a minute dot on the scutellum. Both wings uniform dark brown. Head with some very short erect hair above. Clypeus truncate below; ocelli subequal, in equilateral triangle, the posteriors almost twice as near to eyes as to each other; antennae long and slender, third joint not as

long as fourth, second and third equal to fourth, and almost equal vertex width; the pronotum long, deeply arcuate behind; propodeum smooth, deeply cut out behind and the sides forming rounded lobes; abdomen rather broad on base, compressed behind, a few hairs near tip and on the venter. Legs short, the femur and tibia plainly somewhat swollen, the mid and hind tibiae with numerous minute spines, similar spines arising from pits on the under side of the mid and hind femora; long spur of hind tibia about two-thirds of basitarsus. Wings fairly broad; the marginal cell very long, pointed at each end, hardly one-half its length from wing-tip; second submarginal one-fourth longer than high, receiving the first recurrent at apical fourth; third submarginal nearly twice as long below as the second, but above not as long as the second, and receiving the second recurrent (which is evenly curved) at its middle; in the hind wing the anal vein is interstitial with the cubital fork.

Length 17 mm.; fore wing 15 mm.

From Batraeyon, Mt. Apo, Mindanao, 8000 ft., 14 Sept. (Clagg).

What I suppose is the male has the clypeus white except a basal median black spot, the lower face extending up each side by orbits, a pale line behind eyes, basal joint of antennae pale beneath, the lobes of propodeum are white as in the female, last segment of abdomen white above; the front femora and tibiae are reddish as in the female, but the mid and hind femora and tibiae black, and the tibiae are not as much swollen as in the female; there is a band of white pubescence on the posterior border of the pronotum, and its lower sides are alutaceous, and an alutaceous effect can be seen in certain lights near the tip of the mesopleura; the wings are hyaline, except a cloud over most of marginal cell, second and third submarginals and part of the second discoidal cells; on the abdomen there is a more definite sericeous band on base of first and second segments.

Length 9 mm.

From Calian, 5500 ft., Dec., Mindanao (Clagg).

Minotocyphus gracilis sp. nov.

♀ Black; with silvery pubescence on head, thorax and parts of legs; face with a narrow yellowish line by each orbit; fore wings largely dark brown, the wing tip and the basal third hyaline; hind wings hyaline, a little dusky at tips. Clypeus truncate below; ocelli subequal, posteriors twice as near eyes as to each other; antennae moderate slender, third joint not as long as fourth, second plus third

as long as fourth, but hardly equal to vertex width; pronotum moderately long, almost angulate behind, propodeum rather short, not arched, behind with a broad concavity, the lateral edges in lobes; abdomen polished, with fine hairs near tip and on venter. Legs short; the tibiae less swollen than in *M. obesus*, but the spine pits are on under surface of mid and hind femora, the tibiae with many similar spines and pits; the parallel spines at tip of tibia are very small, scarcely noticeable; long spur of hind tibia a little more than one-half of basitarsus. Wings moderate; the marginal cell fairly long, pointed at each end, not one-half its length from the wing-tip; second submarginal cell one-third longer than high, base scarcely oblique, receiving the first recurrent vein beyond the middle; the third submarginal fully one-half longer than the second below, but above not as long as the second, receiving the second recurrent vein (curved in middle) at about middle; in hind wing the anal vein interstitial with the cubital fork.

Length 8.5 mm.; fore wing 7 mm.

From Mt. Makeling, Luzon.

The male is colored the same, pale orbital lines narrower, antennae thicker, last segment of abdomen white above; mid and hind femora with the spine pits; long spur of hind tibia about two-thirds of the basitarsus; wings hyaline, with a large cloud before tip; hind wings faintly darker at tip.

Length 7 mm.

From Baguio Benguet, Luzon.

CERATOPALINAE.

The peculiar genus, *Xanthampulex*, is considered to belong to this subfamily.

1. Pronotum rounded in front; mesonotum not plainly furrowed. . . *Ceratopales*
 Pronotum truncate in front; mesonotum with two distinct longitudinal
 furrows. *Xanthampulex*

CERATOPALES.

Ceratopales ligea Bingham

Several from Cuernos Mts., Negros, and Surigao, Mindanao, agree with the description of this species from the lower Malay Peninsula; it will not fit any of the Indian species, nor the one from the Riukiu Island.

XANTHAMPULEX.

1. Suprantennal (horseshoe) process contains or is partly covered by a pear-shaped process extending upward; front pale yellow brown; in male the hind basitarsus is somewhat-swollen.....*intrusus*
Suprantennal process shows no such median pear-shaped body, but a horseshoe open above..... 2
2. Front and vertex black..... 3
Front and vertex pale yellow brown..... 5
3. The horseshoe process with broad flattened sides and only a very narrow median line, almost closed at upper end.....*albovariegata*
The horseshoe process with more narrow sides and a fairly wide furrow in middle..... 4
4. The black of vertex does not quite touch the eyes.....*luzonensis*
The black of vertex broadly meets the eyes.....var. *completus*
5. Sides of process elevated, plainly divergent above; propodeum with a very distinct hump each side.....*divaricatus*
Sides of process nearly parallel; no such humps on the sides of the propodeum.....*pernix*

Xanthampulex albovariegata Cam.

One from Sandakan, Borneo agrees with Bingham's description of the Ceylonese specimens, in color as well as in that the suprantennal process has no deep median groove, but only a line, so that the lateral lobes are very broad; the long spur of hind tibia is fully three-fourths of the basitarsus. There are a few dark spots on coxae and base of the propodeum, the mid and hind tarsi dark; the stigma is ferrugineous.

Xanthampulex luzonensis Rohwer.

Described from Los Banos and Mt. Makeling, Luzon; also from Surigao, Iligan, Mindanao. In the male the hind basitarsus is not swollen. In a specimen from Surigao and one from Island of Samar; the black of vertex is more extensive and reaches the top of the eyes; the pleura shows four large whitish spots; the suprantennal process appears to be more prominent, and there is more swelling on the front toward the tumid eye emarginations; the interocellar area is more swollen so that the ocelli sit in the sides of a slight hump, and the posterior ocelli are a little further apart than in the typical form. I shall call it *X. luzonensis* var. *completus*.

Xanthampulex divaricatus sp. nov.

♂ Pale ferrugineous, rather darker at tip of the abdomen; lower

part of head more whitish, vertex and front with the ferrugineous mark occupying almost entire area; tarsi brown, antennae beyond base black; wings clear or scarcely infuscate, no marks, stigma dark brown. Labrum emarginate; clypeus faintly concave below; face rather wider above than usual, the space within the emargination of the eyes is greatly swollen into lobes; very much larger than in *X. luzonensis*; the suprantennal process is larger, the lateral lobes more divergent than usual and with a sharper crest; the ocelli are proportionally rather small, the anterior being only a little larger than the posteriors, these more than two diameters apart and twice as far from the eyes; third antennal joint about three times as long as broad, no longer than the fourth. The pronotum is arcuate behind, the anterior lower corners are prominent; the postscutellum is much elevated, the propodeum has on each side half way from spiracle to tip a very distinct, almost conical, hump; the abdomen is short and compressed toward tip; legs as usual, but the hind tibiae have many very minute, but distinct spines, the hind basitarsus of the male is thick, but hardly fusiform; the long spur of hind tibia about two-thirds of basitarsus; the venation is similar to that of the other species, but the second and third submarginal cells are both somewhat longer, the second recurrent slightly zigzag.

Length 12 mm.

From Mt. Makeling, Luzon; and Cuernos Mts., Negros.

Xanthampulex intrusus sp. nov.

♂ Reddish yellow; antennae beyond the pale base, and the mid and hind tarsi brown to black; the large median spot on front and vertex reaching nearly to antennae and meeting the upper ends of eyes and extending back on the occiput is yellow brown in color (as in *X. pernix*); the wings clear, the stigma brown. Labrum emarginate below; clypeus truncate below; there is a low ridge each side to represent the suprantennal process of *X. luzonensis*, and between them is a swollen pear-shaped body, with the point upward. Antennae shorter than in male of *X. luzonensis*, the third joint being less than three times as long as broad; anterior ocellus somewhat larger than posteriors, latter hardly one diameter apart and fully four times as far from the eyes; some very short hairs on the vertex. Thorax without hair, polished; pronotum arcuate behind, its lower anterior tubercles not as prominent as in *X. luzonensis*; propodeum with a faint median line, no indication of a lateral swelling; abdomen com-

pressed especially behind; legs similar to other species; the hind basitarsus of male is distinctly a little swollen, so that it is fusiform; long spur of hind tibia nearly three-fourths of basitarsus; venation as in other species (*pernix*, *luzonensis*, *albovariegata*).

Length 6 to 8 mm.

From Mt. Makeling, Luzon; and the Island of Basilan.

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THE ROTATION OF COBALT AND NICKEL BY
MAGNETIZATION AND THE GYROMAGNETIC RATIOS
OF THEIR MAGNETIC ELEMENTS.

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THE ROTATION OF COBALT AND NICKEL BY MAGNETIZATION AND THE GYROMAGNETIC RATIOS OF THEIR MAGNETIC ELEMENTS.

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1. INTRODUCTION. In an earlier paper in this journal (Vol. 66, No. 2, 1931, pp. 273-348) I have given an account of an elaborate investigation of the Einstein and de Haas effect (rotation by magnetization) in soft iron and permalloy. In this work the systematic errors were thoroughly studied and eliminated, and the gyromagnetic ratio for each of the two materials was determined with an error probably less than one-half per cent. The ratios found for iron and permalloy are close to $1.04 \times m/e$ and $1.05 \times m/e$, respectively. These are in agreement, within the experimental errors, with the values published in 1925 by L. J. H. Barnett and the author* as the result of an elaborate investigation on the magnetization of ferromagnetic substances by rotation, as well as with the value ($1.02 \times m/e$) obtained from the first investigation on iron when this effect was discovered in 1914.†

In connection with the early part of the investigation on the Einstein and de Haas effect in permalloy and iron published in 1931, experiments were made on nickel also, but the systematic disturbances proved so great that further work on this substance was abandoned until the methods should be thoroughly developed with the more tractable materials. In 1930 work on nickel was resumed. The present paper is devoted chiefly to work on this material and on cobalt.

2. METHODS OF EXPERIMENTATION. The principal work on nickel was done by the chief method described in the earlier paper, to which reference must be made for many of the details, and by a slight modification of this method. For the work on cobalt, and a part of the work on nickel, it was necessary to make some changes of importance, which will be described later (§ § 4, 5).

*S. J. Barnett and L. J. H. Barnett, *Proc. Amer. Acad. of Arts and Sciences*, 60, No. 2, 1925, pp. 125-216.

†See especially S. J. Barnett, *Phys. Rev.* 6, 1915, pp. 239-270.

The discussion of the new work will be facilitated by reference to Fig. 1, which is reproduced, with slight changes, from the earlier paper. The rod, or rotor, *F*, under investigation is axially suspended by a thin German silver wire or strip *D*. Hanging from the lower end of the rotor by a rigid joint is a brass rod *J* carrying parallel mirrors *I* on opposite sides, and, below, a group *L* of small permanent magnets

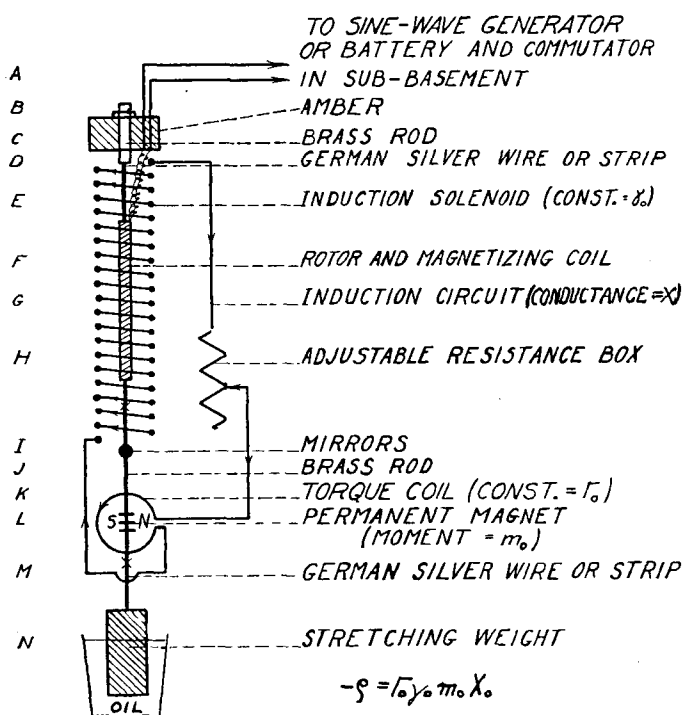


FIGURE 1. Diagram illustrating simplest experimental method.

(magnetic moment = m_0), all turned in the same direction. A heavy brass or copper weight *M* hangs from the lower end of the rod *J* on a second German silver suspension. The weight hangs in a vessel of light oil. Coils of wire surrounding the apparatus and traversed by suitable electric currents neutralize the intensity of the earth's magnetic field almost completely, when desired, in the region occupied by the rotor.

In all of the recent work and most of the earlier work, the magnetizing coil was wound directly upon the rotor F . This eliminates the possibility of certain important theoretical and experimental errors. From a storage battery and commutator, producing a flat-topped wave of electromotive force, current is led to the magnetizing coil by fine wires twisted together and wound into a single loose spiral around the suspension. (In the figure, the wires are shown separate for clearness.) The rotor is surrounded with a much longer uniformly wound cylindrical coil of wire, E , the *induction solenoid* (constant = γ_0); and the group L of small magnets is at the center of a small double coil, K , the *torque coil* (constant = Γ_0), the planes of whose turns are parallel to the magnets.

The coil E is connected in circuit with the torque coil K through an adjustable resistance box H , by which the conductance X of the circuit may be varied at will.

If the first harmonic of the magnetic moment of the rotor is $\mu = \mu_0 \sin \omega t$, the first harmonic of the gyromagnetic torque $-\rho \dot{\mu}$ will be $g = -\rho \omega \mu_0 \cos \omega t = G \cos \omega t$. The variation of μ induces an electromotive force $\psi = -\omega \mu_0 \gamma_0 \cos \omega t$ and a current $\psi X = -\omega \mu_0 \gamma_0 X \cos \omega t$ in the induction circuit. This current, traversing the torque coil, produces a torque $c = -\omega \mu_0 \gamma_0 X \Gamma_0 m_0 \cos \omega t = C \cos \omega t$ on the rotor system. The total impressed torque of frequency $\nu = \frac{\omega}{2\pi}$ on this system is thus $(G + C) \cos \omega t$. The frequency ν of the first harmonic of the impressed electromotive force is, in general, made equal, or very nearly equal, to the natural frequency ν_0 of the vibrating system;* thus the amplitude of the vibration may be written $A = \beta (G + C)$, where β is a constant; or $A = \beta (G - C)$, if, as in practice, the torque coil is so connected in the circuit that c and g have opposite phases. In this case A vanishes for such a value X_0 of X that $G = C$; that is, when $\Gamma_0 \gamma_0 m_0 X_0 = -\rho$. The equation $A = \beta (G - C)$ may be written $A = \beta (G - \alpha X)$, the relation between A and C , or A and X , being linear, as shown in Fig. 2, curve G . The phase of the motion and of the torque change sign together when $X = X_0$; but if we consider only magnitudes, the relation between A and X is given by the two straight lines meeting at $X = X_0$ (corresponding to AF and FB of Fig. 3).

*The rotor will also resound for the impressed frequencies $\nu = 3\nu_0, 5\nu_0$, etc., but with continually diminishing amplitudes for a given amplitude of impressed electromotive force.

If there is an extraneous torque with amplitude Z in phase with g or in the opposite phase, the lines G will be replaced by the lines $G + Z$ or $G - Z$, meeting the axis of abscissae at $X_{0(z)} = X_0 + \delta X_0$ or at $X_{0(-z)} = X_0 - \delta X_0$. If such a torque is present, and its phase can be reversed without altering its amplitude, the true value of X_0 can thus be found by taking the mean of $X_{0(z)}$ and $X_{0(-z)}$.

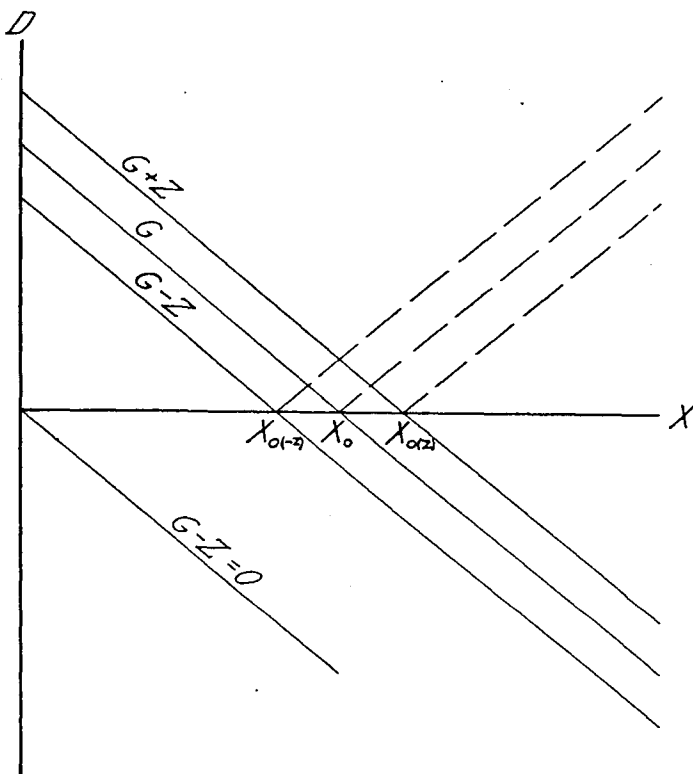


FIGURE 2. Vibration amplitude (D) versus conductance (X) with and without disturbing torques in phase with or in opposition to g .

If there is a torque in quadrature with g , the straight lines meeting at $X = X_0$ will be replaced by the symmetrical curved line CED , Fig. 3, with a minimum at $X = X_0$. Thus no systematic error is introduced by the presence of such a torque in determining X_0 , but

mately zero, the three components of the intensity of the earth's magnetic field; (2) by making observations with the suspended system first in one azimuth and again when turned about the vertical through a half revolution; and (3) by making observations with the commutator (or generator) connected to the magnetizing coil in one way, and then with the connections reversed.

Among earlier investigators only two, J. Q. Stewart* and G. Arvidsson,† have taken the precaution of annulling the vertical part of the earth's intensity; and only one, J. Q. Stewart, has deliberately sought to eliminate what he suspected might be an error due to magneto-striction by adopting the equivalent, in his work, of process (3). This process is necessary to eliminate the effects of inequality in the half cycles of current and magnetization, especially when the magnetizing coil is not wound on the rotor. Even in the cases of permalloy and iron all the processes mentioned are necessary.

The sort of error which may be made in the case of nickel by failing to compensate the vertical intensity is indicated in Fig. 4, which exhibits curves drawn between the vibration amplitude and the current in the coil which was used to neutralize the vertical part of the earth's intensity. The resistance of the induction circuit was made approximately equal to that for which zero amplitude would be obtained if only the gyromagnetic torque were present. If this were the case, the amplitude would be zero, or nearly zero for a current 0.95 ampere in the coil which compensated the vertical intensity, and independently of the magnitude of the current in the magnetizing coil. As the figure shows, the position of the minimum depends in a marked degree upon the current; and for neither of the currents tried does it occur for zero vertical intensity. It was on account of such results as this that work on nickel was postponed until more tractable substances had been investigated.

The disturbing torques due to inequality of half cycles—in spite of great pains taken to make them equal—often have components in phase with (or in opposition to) g with amplitudes which are quite comparable with—and may even be equal to or greater than— G itself. The lines G in Fig. 2 are then replaced by such lines as those marked $G - Z$, $G + Z$, or $G - Z = 0$.

For example, the very difficult rotor Iron C (see § 9, footnote) in one set of observations gave the (uncorrected) values of $\rho \times e/m$ exhibited in Table I.

*J. Q. Stewart, *Phys. Rev.* 11, 1918, p. 160.

†G. Arvidsson, *Phys. Zeit.* 21, 1920, p. 88.

TABLE I.

Position of magnetizing switch	Direct		Reversed	
Azimuth	NPW	NPE	NPW	NPE
$\rho \times e/m$	1.201	1.223	0.917	0.938
Means of $\rho \times e/m$	1.212 (1.070)		0.928	

This is by no means an extreme case for this rotor. Of course, the grater Z in comparison with G , the less reliable is the final mean

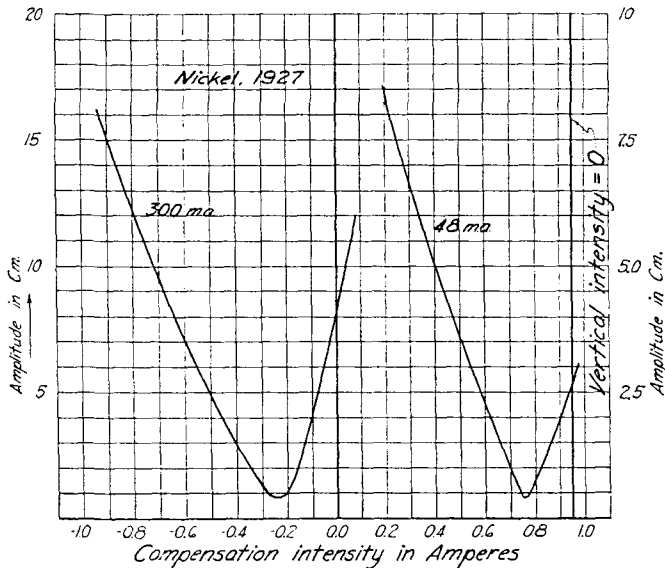


FIGURE 4. Effect of disturbing torques on nickel rotor with vertical intensity of earth's field compensated and uncompensated.

likely to be, as it is not certain that conditions will remain constant throughout the changes needed for the elimination of the effect of Z .

Curves like $G - Z$, $G + Z$, etc. can be obtained with any rotor at will by covering a part of one of the commutator segments with a piece of gummed paper or other insulator. In this way, in the earlier work, it was experimentally proved that the effects of cycle inequality could be eliminated by reversing the magnetizing current switch or by

making an equivalent change. Thus in the case of sine waves the elimination could be made by reversing the generator field. As an example of this latter method some experiments made on the excellent rotor FeI_2 , described in the earlier article, may be cited. These (comparatively rough) experiments were made with the rotor in only one azimuth, there being little difference between results obtained with the two. With the commutator segments equal, the value of $\rho \times e/m$ (uncorrected) was 1.06. When the front of one segment was cut off 1.3 cm. (about 8 or 9 percent) by a strip of gummed paper, the value for one direction of the field was 1.14, for the other 0.96; mean, 1.05. Had it not been for the excellent characteristics of this rotor the difference produced by this large departure from half-cycle equality would have been far greater. For some of our rotors it would undoubtedly have given a positive apparent value of $\rho \times e/m$ for one direction of the field (or switch), and a negative apparent value for the other.

It is only recently that the existence of these torques has been recognized by others, whose experiments on this account have been vitiated by errors of a serious character. In a recent paper Coetier and Scherrer* have stated that the extraneous torque of this kind due to the action of the magnetizing coil (when fixed to the earth) on the rotor is in quadrature with g . This is true of the primary magnetic torque only, but by no means true of the actual effective torque on the rotor, which results from the primary torque and the torque due to the suspension displacement together. We have abundant evidence in addition to that quoted above that the in-phase or in-opposition component of the torque may be very large indeed.

4. METHOD OF REDUCING THE TORQUE DUE TO MAGNETO-STRICTION. When the method of experimentation which had been developed to such a degree of perfection as to yield precise results with permalloy and soft iron was first applied to a cobalt rotor, the disturbing torques were so great as to mask entirely the gyromagnetic torque. As it was probable that magneto-striction was one of the chief sources of the trouble, the construction of the rotor was modified as indicated in Fig. 5. The magnetic rod was mounted coaxially inside a brass tube of somewhat greater length. Three small brass rings with internal diameter just greater than the diameter of the rod, and external diameter just less than the internal diameter of the tube, were soldered around the rod, coaxially, at the center and ends. The

* *Helvetica Physica Acta* 5, 1932, p. 217.

central ring was soldered to the tube also. The center of the rod was thus fastened rigidly to the tube, while the ends were free to slide longitudinally in the tube. The magnetizing coil was wound on the brass tube. This type of construction was adopted with the hope

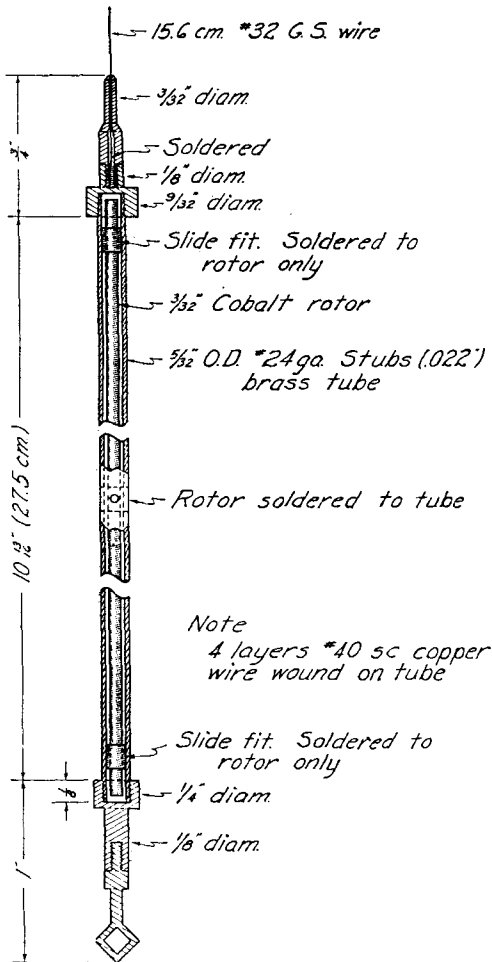


FIGURE 5. Complex rotor designed to eliminate effect of magneto-striction. The new type of head with suspension terminating in spiral soldered in place was used only with Iron C.

that when the magnetostrictive oscillations occurred, the center of mass of the rod would remain fixed and the disturbance would not be communicated to the brass tube and suspension.

The changes greatly improved the behavior of the cobalt, but the disturbing torques were still large. The in-phase component could be corrected for by the process of reversal described above, but the quadrature component was usually too great for any precision.

5. METHOD OF REDUCING THE QUADRATURE TORQUE. It thus became necessary to add a device to annul this quadrature component. The torque coil formerly used was replaced by a pair of coils *F* and *G*, Fig. 6, as nearly alike as practicable, and wound twin. A second

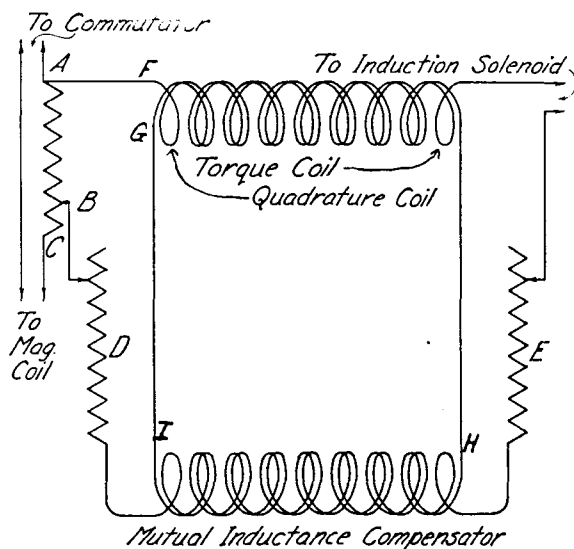


FIGURE 6. Arrangement for compensating quadrature torques.

pair *H* and *I*, also wound twin and as nearly like *F* and *G* as practicable, was constructed. *F* and *G* were mounted in the position of the coil formerly used, and *H* and *I* were mounted at a distance. *G* and *I* were connected in series in the induction circuit, while *F* and *H* were connected in series through an adjustable high resistance box *D*, either directly to the terminals of the commutator, or, as was nearly always the case, to a non-inductive variable rheostat *AC* in series with the magnetizing coil. The two sets of coils were so connected

that the mutual inductance between FH and GI was zero or very small.

A small variator, one of whose two coils was connected in each circuit, made it possible to neutralize the mutual inductance exactly; but this was unnecessary.

With the rectangular waves used the electromotive force between the terminals of the commutator and the magnetizing current were very nearly in phase with one another and in quadrature with the gyromagnetic torque. Thus the current in the coils FH , and, therefore, the torque exerted by F on the vibrator magnet, were very nearly in quadrature with the gyromagnetic torque. By altering the resistance D in series with FH , or the resistance of the conductor AB across which the leads were shunted, and by interchanging the leads if necessary, it was thus possible to reduce any quadrature torque present to a very small quantity.

6. SYSTEMATIC ERRORS DUE TO THE QUADRATURE COIL. The adoption of this arrangement introduces three possible new sources of systematic error. In the first place, the current in FH may not be *exactly* in quadrature with the gyromagnetic torque g . In this case a torque in phase with g (or in opposition) must result from the direct action of F on the vibrator magnet. The constants of the circuits and the method of experimentation (with flat-topped waves) insure, however, that such a torque cannot in any case exceed a small fraction of the quadrature torque, and, in general, a smaller fraction of g . The effect of any such residual torque, moreover, would be completely eliminated in each half set of observations if the current in the quadrature coil were made identical for both directions of the switch controlling the magnetizing current, since the resistance AC (Fig. 6) is in series with the magnetizing coil, and thus the connections of both to the commutator are reversed together. In the actual work this elimination is not made completely, because the quadrature current is given different values for the two directions of the switch. This is necessary or desirable because there are in general other quadrature torques in addition to those due to the half-cycle inequalities.

In the second place, when the mutual inductance M between FH and GI is not zero, the current in the quadrature coil will induce in the induction circuit a current nearly in phase with (or in opposition to) the gyromagnetic torque g . If I is the amplitude of the current in the quadrature coil F , the amplitude of the current induced in GI will be $MI\omega/R$, where $\omega = 2\pi \times$ the frequency and R is the resistance

of the induction circuit. The ratio of the amplitude of the in-phase (or in-opposition) torque thus produced by the quadrature coil to the amplitude of the quadrature torque itself, since F and G have practically the same constant Γ , is $M\omega/R$. This would be entirely negligible even if the mutual inductance between F and G were not almost completely neutralized by that between H and I , M being thus made nearly zero.

In the third place, the effect of the presence of the quadrature circuit, which always has a high resistance, is to diminish slightly the (already negligible) inductance of the induction circuit (containing GI), and to increase slightly its resistance from R to $R + \delta R$. If

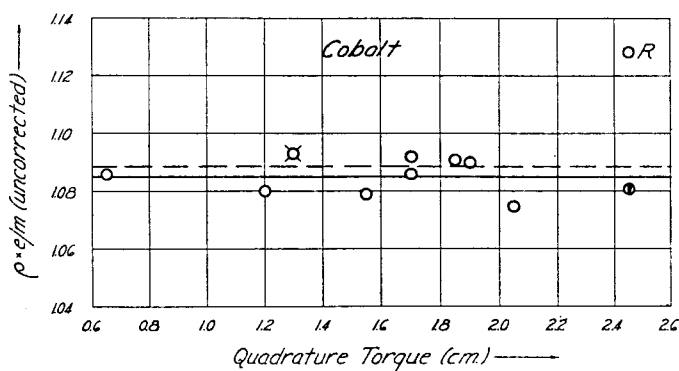


FIGURE 7. Apparent gyromagnetic ratio *versus* quadrature torque (Cobalt IV). The point marked R was rejected for the solid line, and retained for the broken line.

the value of R (or $X = 1/R$) uncorrected for this effect were used in the formula for calculating ρ , the value of ρ obtained would be too great by the fraction $\delta R/R$. It is easy to show that with the constants of the circuits used in this work $\delta R/R$ would be entirely negligible even if the mutual inductance between F and G were not compensated at all by that between H and I ; and $\delta R/R$ is proportional to the mutual inductance M , which, because of the compensation, all but vanishes.

The first mentioned of these three torques is thus the only one which could possibly produce any appreciable error in the work described here. That it also was too small a fraction of g to be detected (and that all three together were too small to be detected) is proved by Fig. 7, in which the calculated values of the gyromagnetic ratio

(uncorrected for coil moment and electron inertia) for the rotor Cobalt IV is plotted as a function of the original quadrature torque acting when the resistance of FH was made infinite. This torque is expressed in terms of the mean minimum amplitude of the vibration on the vibration-amplitude *versus* conductance curve. It is evident from the curve that if there is any in-phase (or in-opposition) component present, it is too small to produce an appreciable effect on the determination of ρ . If the in-phase or in-opposition torque were appreciable, it could be eliminated by extrapolating to zero residual amplitude. Fig. 8 gives a chart constructed in the same way for the rotor Nickel III.

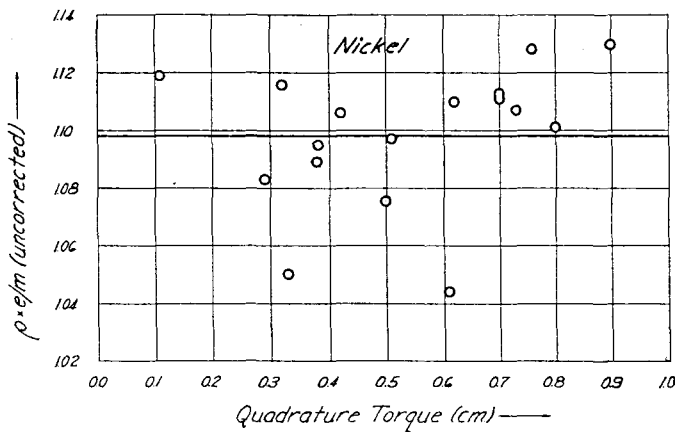


FIGURE 8. Apparent gyromagnetic ratio *versus* quadrature torque (Nickel III).

7. THE NICKEL ROTORS. Successful observations on the gyromagnetic ratio were made with three nickel rotors, two of them similar in general construction to the standard rotors of permalloy and iron and of the same length. The first, Nickel I, was $5/64$ inch in diameter and was wound with 4 layers of SC No. 40 copper wire. For a current of 100 m.a. in the coil its magnetic moment was 649 e.m.u. The moment of the magnetizing coil alone was about 4.5 e.m.u.

The second rotor, Nickel II, was $1/16$ inch in diameter, and was wound in the same way. Its magnetic moment, for a current of 100 m.a., was 232 e.m.u.; and the moment of its coil, for the same current, was about 2.2 e.m.u.

The third rotor, Nickel III, was of the more complex type described in § 4. The length of the rotor was about equal to that of the others. The diameter of the magnetic material was $\frac{5}{64}$ inch, and the outer diameter of the brass tube was $\frac{5}{32}$ inch (4.0 mm.) The brass tube was wound with four layers of No. 40 SC copper wire. Its magnetic moment for a current of 100 m.a. was 360 e.m.u. The moment of the coil alone was about 12 e.m.u.

All the magnetic material was annealed.

8. OBSERVATIONS AND RESULTS FOR NICKEL. Five groups of observations were made on the three nickel rotors, and the results are given in Table II. Some of the observations were made like the

TABLE II.

The Gyromagnetic Ratio for Nickel.

1	2	3	4	5	6	7	8
Group	Rotor	Sets	Frequency	Correction	Range	Gyromagnetic Ratio	Approximate Mean Amplitude
I	Ni I	11	10/sec	$m/e \times -0.006$	$m/e \times 0.023$	1.045 ± 0.005	2.5 cm.
II	Ni I	11	10	-0.006	0.015	1.074 ± 0.003	2 cm.
III	Ni II	6	12.8	-0.009	0.088	1.050 ± 0.033	3 cm.
IV	Ni I	15	10.3	-0.006	0.014	1.059 ± 0.003	6 cm.
V	Ni III	17	5.44	-0.031	0.086	1.067 ± 0.018	2 cm.

last series described in the earlier paper (See Table 51-1, p. 343); but in the modification of the method used in much of the work observations had to be made for two values of the resistance of the induction circuit (in addition to ∞) in order to interpolate for equal amplitudes. This of course increased the time necessary for a complete set of observations considerably. The frequencies of the rotors in the brass tubes were so low, and the time necessary for the amplitudes to reach their steady values so large, that with these rotors a period of over seven hours was required for one complete set (including the preliminary and final measurements of compensating currents, etc.).

In Table II, column 1 gives the order in which the different groups of observations were made; column 2, the designation of the rotor; column 3, the number of complete sets in the group; column 4, the

frequency; column 5, the correction to the observed value of the gyromagnetic ratio due to the moment of the magnetizing coil and to electron inertia, combined, which were not otherwise taken account of in the calculations; column 6, the range over which the gyromagnetic ratio fluctuated in the group; column 7, the mean value of the gyromagnetic ratio and its mean error; and column 8, the approximate mean vibration amplitude.

The results for Group I, in spite of the small average error, are somewhat uncertain on account of the fact that the moment of the vibrator magnet was not so well known as it usually was; but the uncertainty in the moment was by no means so great as the discrepancy between the results of I and those of some of the other groups. The results of Group II on the same rotor are considerably superior. Through an accident, the fundamental frequency of the electromotive force applied to the rotor in both these groups was made three times the natural frequency of the rotor, which accounts for the small amplitudes obtained. See §2, foot-note.

Group IV, on the same rotor, is considered far more reliable than either I or II. The mean result for I and II, viz. 1.060, is almost identical with the result of IV.

The mean error for Group III, on Nickel II, is much greater than that for any of the other groups. In spite of great pains taken in its construction, this rotor was exceedingly difficult to work with, doubtless on account of asymmetry. The extraneous torques, both in-phase and in-quadrature, were large, and the results are considered less reliable than those of any other group.

The mean value of $\rho \times e/m$ from Group IV, viz. 1.059, agrees closely with the (much less precise) mean from all the other groups, viz. 1.057, and is probably correct within less than 1 per cent. Comparatively little weight should be attached to the smaller value of Group III.

9. ROTORS OF COBALT. Four cobalt rotors were constructed, all of them from material presented by the Bell Telephone Laboratories. This consisted of 92.4 percent cobalt, 4.2 percent copper, 1.5 percent iron, and 1.8 percent nickel. The copper was added to make the material less difficult to work. Three of them were made like the simple wound rotors previously described. Of these three rotors, one was $3/32$ inch in diameter and annealed, another was $1/8$ inch in diameter and annealed, while the third was $3/32$ inch in diameter and was not annealed. All were wound with 4 layers of No. 40 SC copper wire. For the reason given above it was impossible to secure satisfactory determinations of the gyromagnetic ratio with any of

these rotors. A fourth rotor, designated here as Cobalt IV, of the same material, 3/32 inch in diameter and annealed, was constructed like the complex nickel rotor Nickel III already described. The coil was almost exactly similar to that of Nickel III. The moment for a current of 100 m.a. in the coil was 1138 e.m.u. In spite of many efforts I have not yet succeeded in getting suitable material for the construction of rotors of pure cobalt.*

TABLE III.
The Gyromagnetic Ratio for Cobalt.

1	2	3	4	5	6	7	8
Group	Rotor	Sets	Fre- quency	Correc- tion	Range	Gyro- magnetic ratio	Approxi- mate Mean Amplitude
I	Co IV	13	5.52/Sec.	$m/e \times$ -0.010	$m/e \times$ 0.054	$m/e \times$ 1.081 ± 0.009	4.5 cm.
I'	Co IV	12	5.52/Sec.	-0.010	0.018	1.077 ± 0.006	4.5 cm.

10. OBSERVATIONS AND RESULTS FOR COBALT. The results of the observations made with the quadrature torque compensated are given in Table III, constructed like Table II.

**Complex rotor of iron.* Another rotor, of iron, designated as Iron C, was made in the same way of some material kindly furnished by Professor Honda, whose description has not yet reached me. It was 5/64 inch in diameter and was turned down from a thicker rod composed of several single crystals. It was then carefully annealed. This rotor was exceedingly difficult to work with, the in-phase and quadrature disturbing torques being both very large and more or less variable. For reasons which are not understood, the lower end of the suspension repeatedly pulled out of the rotor, causing the magnet-mirror system to fall. This difficulty was remedied by remodeling the rotor cap and method of attachment of the suspension as shown in Fig. 5, the lower end of the suspension being coiled up and soldered inside the cap. With other rotors also we have sometimes been troubled with the pulling out of the lower end of the suspension, in spite of great pains to prevent it, and have suspected this due to magneto-striction, whose effects do not vanish even in the complex rotors. The mean value of $p/m/e$ obtained with this iron rotor is 1.048; but relatively little weight is to be attached to this result, as the observations, in spite of great care and much labor, are far inferior to those obtained earlier with Armco iron. (See § 3 above for remarks on the magneto-strictive effects with this rotor.)

As the table shows, thirteen complete sets of observations were obtained with Cobalt IV giving for $\rho/m/e$ the mean value 1.081 ± 0.009 . The first set of observations, obtained when the new type of rotor was used for the first time, gave a result much greater than any of the others, as indicated by the point marked *R* in Fig. 7. If this observation is rejected the result is 1.077 ± 0.006 . This value is probably correct within 1 percent.

11. GENERAL CONCLUSIONS. While the results obtained in this investigation on cobalt and nickel are not so precise as those obtained on permalloy and soft iron, they are believed far more reliable than any other results hitherto published by others on rotation by magnetization, or the Einstein and de Haas effect, on account of the more nearly complete elimination of the systematic errors.

Like the results on permalloy and soft iron in the author's earlier paper on rotation by magnetization, the results given here are in complete accord, within the limits of the experimental errors, with those obtained by L. J. H. Barnett and the author in their work on magnetization by rotation. In that work the mean value of ρ for all the ferromagnetic substances investigated was $1.059 \times m/e$. In the present work, on the converse effect, the mean value for iron (1.037), permalloy (1.049), nickel (1.059), and cobalt (1.077) is $1.055_5 \times m/e$. The agreement is remarkable in view of the fact that many serious systematic errors had to be eliminated in each investigation, and the fact that the errors were of entirely different kinds in the two researches.

12. SPECIAL ACKNOWLEDGMENTS. While this paper is a sequel to the 1931 paper referred to in § 1 and elsewhere above, the new work overlaps the older to a considerable extent, and I must again express my obligations to the assistants mentioned when the earlier work was published. In addition I desire to thank Dr. Vaino Hoover who has helped me in the more recent part of the work. I have continued to be greatly indebted to the Carnegie Institution of Washington for the use of equipment, and to the Board of Research of the University of California and to the California Institute for their support. To the late Dr. H. D. Arnold, and the Bell Telephone Laboratories, I am again indebted for material; and for other material I have to thank Professor Honda. The experimental work has been done in the Norman Bridge Laboratory of the Institute.

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THE VAPOR PRESSURE OF WATER.

PART II. STEAM RESEARCH PROGRAM.

By

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(Contribution from the Research Laboratory of Physical Chemistry,
Massachusetts Institute of Technology, No. 300.)

THE VAPOR PRESSURE OF WATER.

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THE measurements reported in the present paper were obtained by the so-called static method wherein a mass of fluid in a two-phase condition is confined at constant temperature and the pressure observed. Measurements by the dynamic method, where the fluid is moving continuously, have recently been published by A. Egerton and G. S. Callendar² who carried out measurements from 170° C to 374° C. Quite recently also our colleagues in the steam research program sponsored by the American Society of Mechanical Engineers, have published the results of vapor pressure measurements obtained by the static method at the United States Bureau of Standards.³ There are therefore available the results of three new and independent investigations of water vapor pressures, one by the dynamic or continuous flow method and two by the static method. The vapor pressure values by both methods should be identical up to the point where, in the dynamic method, the flow becomes sufficiently rapid to influence or interfere with the rate of attainment of equilibrium of the molecules of vapor and liquid at constant temperature. The comparisons to be effected in a later section show that the final results of all three investigations are in remarkably good accord.

The results of the measurements at the Research Laboratory of Physical Chemistry have been presented at the Autumn meetings of the steam research group during the time of the regular A. S. M. E. meetings and published usually in the February issue of *Mechanical Engineering*.⁴ The first report of vapor pressure values was in Decem-

¹ The present paper is the second of a series of papers reporting the results of the Massachusetts Institute of Technology program of steam research promoted by the American Society of Mechanical Engineers through the material support of the steam power industries.

² A. Egerton and G. S. Callendar, *Phil. Trans. Roy. Soc. London* **231**, 147 (1932).

³ N. S. Osborne, H. F. Stimson, E. F. Fioch and D. C. Ginnings, *Bur. Stan. Jour. of Research*, **10**, 155 (1933).

⁴ *Mech. Eng.* **48**, 153 (1926).

ber 1925 and in the intervening time measurements of the pressure, volume and temperature for the two phase states, the homogeneous liquid and homogeneous gaseous state, have been presented regularly at the annual meetings. During the whole course of the investigation improvements in apparatus and technique developed, but an item of the greatest importance was the choice of container material. This has already been discussed in the preceding paper, Part I of the series, but a brief reference to the container is desirable in the present paper if only to emphasize the wholly satisfactory behavior of the 18 percent chromium, 8 percent nickel steel (trade name Nirosta) used at M. I. T. in the last years of the steam investigation. A similar alloy containing 4.5 tungsten has been found equally satisfactory by Nathan S. Osborne and his coworkers at the U. S. Bureau of Standards.

The measurements of vapor pressure made up to March 1930 were critically examined and smoothed by adjusting consecutive differences of the logarithms of the pressures and a table was prepared for each degree centigrade.⁵ A table of derivatives was also prepared by a very convenient method of computation due to Rutledge.⁶ The M. I. T. values of pressure were in fair agreement with the values of the Reichsanstalt⁷ corrected to the international platinum resistance temperature scale⁸ to 300° C. Above the latter temperature the Reichsanstalt values appeared increasingly low by comparison and at 370° C. the difference amounted to 1 in 750.

During 1930 containers of the Chrome-nickel steel had become available and measurements of the volumes of superheated steam were in progress. It was not, however, until 1932 that a systematic series of new measurements on vapor pressures was carried out using the new steel for the container and an apparatus especially designed for the work. The new data proved to be more consistent than the earlier results and, moreover, in good agreement with those of our colleagues at the Bureau of Standards. The agreement with the data of Egerton and Callendar is also excellent.

THE TEMPERATURE MEASUREMENTS.

The older series of measurements were made with a platinum electrical resistance thermometer⁹ constructed in 1920 of inferior wire.

⁵ F. G. Keyes and L. B. Smith, *Mech. Eng.* 53, 132 (1931).

⁶ G. Rutledge, *Jour. Math. and Phys. M. I. T.* 8, 1 (1929). *Phys. Rev.*, 40 262 (1932).

⁷ *Int. Crit. Tables* III, p. 233.

⁸ G. K. Burgess, *Bur. Stand. Jour. of Res.* 1, 635 (1928).

⁹ See Part I, p. 523.

It was not until the end of 1923 that wire having a temperature coefficient of 0.00392 or greater became available. Thus the early measurements were made with an unsatisfactory resistance thermometer whose indications were, however, finally determined in relation to a thermometer constructed of satisfactory platinum. Unfortunately the comparisons could not be made of the identical thermometer used in the vapor pressure measurements but with one of the same construction and wire. The temperatures in the vapor pressure measurements herein recorded, and in fact all the steam work, are those indicated directly or indirectly through suitable comparisons by a potential terminal type platinum resistance thermometer,¹⁰ No. 4BS, having a temperature coefficient of 0.00392228 and δ constant 1.4965. In the last series of measurements made in 1932 using Nirosta steel and subsequent to 1926, the measurements of temperature were all directly indicated by thermometer No. 4BS.

The calibration of the resistance thermometers was carried out by using the ice and normal boiling temperature of water and the normal sulphur boiling temperature assumed to be 444.6. The latter fixed points reproduce the international temperature scale when platinum of the requisite purity is used. The ice point resistance was observed many times during the course of all the steam work and varied by a few units of 10^{-4} ohms in the course of six years. The type of steam point apparatus employed embodies all the features required to give reproducible and exact results when operated against the atmospheric pressure. Readings in the course of several years were consistent to $\pm 0.0013^\circ$ and show a maximum deviation of 0.002° . The sulphur point apparatus is of glass electrically heated with elaborate radiation shielding for the thermometer. The readings were consistent to $\pm 0.009^\circ$ with a maximum deviation of 0.013° .*

Taking into consideration the consistency of the calibration data of the thermometers used in the vapor pressure measurements combined with general laboratory experience with dozens of platinum resistance thermometers constructed in this laboratory during the past twenty years we believe that the international scale of temperature as

¹⁰ See Table 3, Part I.

* Further improvement in reproducibility of the boiling point temperature of sulphur has been secured by J. A. Beattie and J. M. Gaines using an "artificial" or controlled atmosphere adjusted closely to 760 mm. pressure. By this means the sulphur boiling temperature can be reproduced to ± 0.003 when nitrogen is used instead of air in the artificial atmosphere apparatus.

realized should not deviate by more than $\pm 0.01^\circ$ C. from the indications of similar thermometers constructed in other laboratories. It is scarcely necessary to state that a thermostated and periodically calibrated bridge was used for all resistance measurements.

THE PRESSURE GAUGE.

The particular form of gauge used and the mode of detecting pressure equilibrium has been described in Part I. The sensitiveness of the device is very great and the indication is that the pressure reproducibility during calibration is about one in twenty thousand.¹¹ Thus at 300° the pressure is 84.78 International atmospheres, which on the basis of the latter precision should be determinable to 0.0042 atmospheres. The rate of change of pressure with temperature at 300° is, however, 1.194 atm. per degree and 0.0042 atm. therefore corresponds to, or would require, a reproducibility of at least 0.0035° in the temperature scale. The latter number, however, is less than the reproducibility of the temperature scale since the sulphur boiling point determinations may actually deviate by as much as 0.013° degrees. Taking 0.01° as the temperature scale reproducibility it appears that one in seven thousand should be approximately the agreement between independent observers at 300° and this proves to be, roughly, the order of agreement attained at this temperature by the recent independent investigators. As the reproducibility of the temperature scale is improved the possibility of greater accord seems in prospect.

The gauge No. 52 whose constant was about 0.5 mm. per gram (actually 0.49681 mm. per gram, July, 1932) was used during 1932 in the measurements at the lower pressures and it was sensitive to a fraction of a gram. Gauge No. 28 whose constant was 1.99770 mm. per gram in June, 1931, was used for all pressures in excess of 20 atm. Gauge No. 1T having a constant 1.01443 in July, 1923, was likewise used in measurements up to March 1931.

All weights applied to the piston gauge during calibration or for pressure measurements were compared with standard weights certified by the U. S. Bureau of Standards. The resulting corrections to the weights were computed to give the correct relation to the international kilogram when used in air at 76 cm. and 25° C. The variation of the air density from that corresponding to the latter pressure and temperature was neglected since in Cambridge the extremes of pres-

¹¹ F. G. Keyes and Jane Dewey, *Jour. Opt. Soc. Am.* 14, 491 (1927).

sure are rarely greater than ± 1 cm. from 76 cm. The weight of the piston and all necessary parts, scale pan, etc., contributing to the force exerted on the piston were also similarly determined in terms of the international kilogram. In reducing the pressure observations it was of course necessary to know the relation of the value of gravity at the place where the gauge was used to the standard value of gravity 980.665 cm./sec.² The value of gravity at this laboratory is 980.397 and depends on observations made at the Harvard Observatory nearby. The known thermal dilation of steel suffices to compute the temperature correction of the gauge when the temperature of the latter differs from 30° C, the temperature at which all piston gauge constants is referred.

The piston-cylinder of the R. L. P. C. type of pressure gauge is of hardened steel and exhibits a slow diminution of the effective area with time. Numerical data for the effect is contained in Table IV, Part I, and data for a number of gauges has been published elsewhere.¹² The actual change of the constant with time was largest for the case-hardened No. 1T piston, and during about eight years the change per year of the constant diminished from 0.0182 percent to 0.0165 percent. The constant of the uniformly hardened piston and cylinder of No. 28 gauge increased by 0.0122 percent per year during about four years while the constant of No. 52 gauge having the largest effective diameter (1.37 cm.) increased at a uniform rate of 0.0091 percent per year over about five years. The increase in the gauge constant with time has been found by Dr. Beattie and his collaborators to have essentially the same value for gauges in continuous use and for gauges used only as standards, consequently the "wear" of the piston-cylinder has no connection with the ageing effect. The time rate of change of the constant was of course given consideration in the reduction of all pressure readings.

It is apropos to refer to the convenience of the carbon dioxide vapor pressure at the ice point,¹³ 34.4009 ± 0.0013 International atmospheres, as a pressure calibration standard. The latter value found by Bridgeman has recently been confirmed by the measurements of C. H. Meyers and M. S. Van Dusen¹⁴ who give 34.3974 International atmospheres for the vapor pressure of carbon dioxide at zero degrees.

¹² J. A. Beattie and O. C. Bridgeman, *Ann. d. Phys.* (5) 12, 827 (1932).

¹³ O. C. Bridgeman, *J. Am. Chem. Soc.*, 49, 1174 (1927).

¹⁴ C. H. Meyers and M. S. Van Dusen, *U. S. Bur. of Stand. Jour. of Res.* 10, 391 (1933).

Carbon dioxide is easy to prepare in a state of purity, and the ice point, without excessive precautions, can be reproduced to 0.002°C corresponding to about one in twenty thousand in the pressure. Once the apparatus for pressure calibrations is available the determination of a gauge constant can be carried out in a small fraction of the time required where a mercury column is used.

CONSTANT TEMPERATURE BATH.

The temperature bath at the beginning of the steam work in 1922 was not capable of being automatically regulated to constancy of temperature better than $\pm 0.01^{\circ}$. By 1926, however, the regulation had been improved to $\pm 0.002^{\circ}$, and further refinement was not sought. The lithium, sodium, potassium nitrates mixture was unsuitable for measurements lower than 140°C and no measurements made below 150°C are recorded. The bath was used to 460°C and was entirely satisfactory in its operation at this temperature.

It was comparatively easy to adjust the energy applied at a value whereby temperature regulation would automatically be maintained at round temperatures. Thus all observations of vapor pressures and other properties were made for the most part at even ten degree intervals beginning with 150°C as indicated by thermometer No. 1 or No. 4 BS. The uniformity of the temperature of the bath is attested to by the constancy of temperature finally attained in 1926, namely $\pm 0.002^{\circ}\text{C}$. Exploration of the bath with respect to the temperature of different portions also indicated that extreme variations were not sensibly greater than 0.002° . The thermometer during measurements was of course actually placed near the water container.

EXPERIMENTAL PROCEDURE.

The method of preparing air free water and introducing the latter into the containers has already been described in Part I. It is now believed that possibly some gas evolution may have resulted by the interaction of water and nickel at the higher temperatures. The design of the apparatus permitted a variation of the relative volumes of vapor and liquid up to the point of complete collapse of the vapor phase, and in the course of the measurements of vapor pressure successive readings were taken with diminishing vapor volumes. No significant rise in vapor pressures was observed, but the procedure may not be sufficiently sensitive as a test for permanent gas when a large quantity of liquid water is present.

The design of apparatus, Fig. 18, Part I, used with the Nirosta container, No. 3 B, in 1932 permitted the convenient expulsion by evaporation of part of the water sample between measurements as well as the collapsing of the vapor phase. As a result of our experience we believe that no permanent gas is generated at temperatures as high as 460° C when the 18 percent-8 percent chrome-nickel alloy steel is used for the containers.

The determination of the oil, mercury and water levels is of great importance in reducing the observations. The determination of the levels differed in detail, however, according to the apparatus used. The early measurements wherein the No. 1 container of nickel was used involved a variable mercury column dependent on the setting or position of the piston of the volumnometer. (See Fig. 9, Part I.) This is likewise the case when the spherical container No. 2 or No. 2 B is used but in the latter case the levels of the mercury actually in the spherical portion of the container was computed from the setting of the volumnometer which measured the amount of mercury injected into the container. The vertical height of mercury in the sphere designated by x is thus determined for a given volume, V , of mercury injected, by the formula $V = 1/3 \pi x^2 (3r - x)$ where r is the radius of the sphere. The uniform bore of the riser G was determined and the volumes of the connecting portions at the end of G were likewise ascertained. It was therefore possible to determine the level of mercury in G relative to the insulated needle tip at H from the reading of the volumnometer I .

From Fig. 9 it is clear that water levels and oil levels must also be determined. The pressure effect of the oil column is substantially constant since the position of the piston of the gauge when in use was maintained at a fixed point and the density variation of the oil with pressure is small. The part of the water column in the container where water is the confining fluid varies greatly in density and must be computed from a knowledge of the total mass of water in the system, the internal diameter of the container, and the densities of the vapor and liquid phases of water. With these data it is possible to compute the container water level at any temperature and pressure from the reading of the volumnometer. The capillary connecting tube contains water at the temperature of the bath, at the graded temperature between the level of the bath fluid and the bath cover at the temperature of the surrounding air and at 30°. Besides this attention must be given to the column of water in the riser G , Fig. 9. The data

required for computing the pressure effects of all parts of the water column was either known or determined during the course of preparing the apparatus for a series of measurements. The pressure effect of the column of vapor in the container was also computed in deducing the pressure at the surface of separation of the liquid phase and the vapor phase.

In the case of the apparatus, Fig. 18 Part I, the level of mercury in the riser *G* contributed nothing to the pressure within container *E*. The volumnometer did, however, enable the water level within container *E*, of known internal diameter, to be determined with precision even though the exact mass of water within *E* was unknown. Thus the distance between the inside top of *E* and the needle point *F* contacting with mercury in *L* being known, water may be forced from *G* into *E* by means of the volumnometer *I*. This is continued until, from the rise in pressure, *E* is known to be completely filled with water. On withdrawing the piston of the volumnometer the exact volume of water vapor space within *E* may be computed using the known values for the density of water. Since the internal diameter of *E* is known the distance between the water level and the top of *E* may be computed.

The difference in mercury levels in *L* was a small fraction of a millimeter and very easily determined. The oil level between *J* and the bottom of the gauge piston was likewise easily determined and from its known density as a function of pressure and temperature it was possible to compute the oil line pressure contribution.

RESULTS OF THE MEASUREMENTS.

All of the results of our efforts to measure the saturation pressure of water are tabulated in Tables 1, 2 and 3, classified as series 1, series 2 and series 3. In the first columns of the tables there will be found the date of the observations; in the second the container type is designated in accordance with the designations of Table II, Part I; in the third the temperature is given and the thermometer designated, while the fourth column contains the measurements corrected to give the pressure (in International Atmospheres)* of saturated vapor at the contact of the liquid phase within the container. Under each group of data p_m designates the arithmetical average of the group of ob-

* The International atmosphere is defined as the pressure exerted by a column of mercury 76 cm. in length at 0° (density of mercury 13.5951) subject to gravitational acceleration of 980.665 cm./sec.².

servations while P_{calc} denotes the pressure computed by means of an equation believed to reproduce with tolerable faithfulness our latest and most satisfactory measurements. The number following Δt is the magnitude of the temperature difference which corresponds to the difference in pressure $p_m - p_{calc}$.

Each datum represents the mean of several independent readings or settings of the pressure gauge and corresponding readings of the temperature deduced from the resistance thermometer bridge. No two readings moreover, at any temperature, correspond to the same ratio of liquid to vapor within the container and in many instances, particularly when No. 3 B container was used, withdrawals of water were made without causing any change in the vapor pressure.

The difference between the pressures p_{calc} and p_m in the first series is relatively large, particularly at the higher temperatures where p_m is consistently greater than p_c beginning with 300° . Below 300° the differences are consistently lower. All the No. 1 series of measurements were made in the nickel container No. 1 or the spherical machinery steel container No. 2 where the water was confined with mercury.* Moreover, a considerable number of the measurements were made before the regulation of the bath was improved in 1926.

The measurements in series 2 were all carried out in the cylindrical 18 chromium-8 nickel or Norosta steel container No. 1 B during the course of the measurement of the liquid and vapor phase volumes. In this series the accord of the p_m values with p_{calc} is much more satisfactory than in series 1 and the average deviation expressed as Δt is 0.0099° . There is, moreover, no particularly consistent drift of p_m relative to p_{calc} .

Series 3 are the final measurements made in the special apparatus using container No. 3 B of Nirosta steel. These values of the vapor pressures, together with similar data of Series 2, were computed to average values and used as a basis for determining the constants of a smoothing function of the form $\log p = f(T)$. The averaging of the two series was carried out in the following way. The average value of the vapor pressure in series 2 was used as a single datum and averaged with the measurements at each corresponding temperature of the series 3. This procedure was adopted because of the fact that the liquid columns in the series 2 measurements involved three liquids and was less simple compared with the series 3 measurements. The

* Correction was made for the vapor pressure of the mercury taking account of the Poynting effect.

averaging procedure adopted evidently amounts to weighting in favor of the series 3 measurements.

A large number of empirical functions to relate the pressure to the temperature were tested and the form selected was as follows where x stands for $(T_c - T)$; p_c , T_c representing the critical pressure and temperature.

$$\log_{10} \frac{p_c}{p} = \frac{x}{T} \left[\frac{a + bx + cx^3 + ex^4}{1 + dx} \right]. \quad (1)$$

$p_c = 218.167$ Int. atm.; $\log p_c = 2.3387890$; $T_c = (374.11 + 273.16)$,

$a = 3.3463130$, $b = 4.14113 \times 10^{-2}$, $c = 7.515484 \times 10^{-9}$,

$d = 1.3794481 \times 10^{-2}$, $e = 6.56444 \times 10^{-11}$.

The constants a , b , c , d , and e were determined using the least square procedure and employing the 27 values of the averaged saturation pressures listed in column 2 of Table 4. The values of the saturation pressure of water at 110, 120, 130 and 140 as given in the International Critical Tables based on the Reichsanstalt values were also included in the least square computing of the constants. The value of the vapor pressure at 100° namely one International atmosphere, was moreover heavily weighted and is exactly given by the formula using the constants tabulated. In Table 4 there will be found a compilation of pressures extending from 100° to the critical temperature for each ten degrees wherein the observed values of the vapor pressures by Egerton and Callendar, by Osborne, Stimson, Fiock and Ginnings, and by the writers are listed together with corresponding values computed with the smoothing functions proposed by the two later groups of investigators. Differences between the results of the three investigations have been listed in columns 7 to 11 and finally the values of dp/dT as computed from the differentiated smoothing equations used by the Bureau of Standards group and the Massachusetts Institute of Technology group.

The differences in the pressures at corresponding temperatures are on the whole small. The differences between the results obtained at the Bureau of Standards by Osborne, Stimson, Fiock and Ginnings and by the authors ($p_{obs. \text{ B. S. }} - p_{obs. \text{ M. I. T. }}$) tend on average to be smaller (mean p_m is 0.01043 atm.) than the average of the differences between Egerton and Callendar's results and the authors' observed pressures (p_m is 0.01953 atm.). The similar average differences for the Osborne, Stimson, Fiock and Ginnings observed pressures and the

Egerton and Callendar observed pressures is 0.01794 atm. The average value of the differences between the authors observed results and the pressures computed with equation 1 amounts to 0.00376 atm. while the similar average of the differences for the Osborne, Stimson, Fiock and Ginnings' observed and computed pressures is 0.00219 atm. or about 42 percent smaller. The average differences for the computed Osborne, Stimson, Fiock and Ginnings pressures and the authors' computed pressures is 0.01327 atm. or somewhat greater than the average of the differences (0.01043 atm.) between the observed pressures. The bulk of the data for all three investigations are in agreement to substantially 4 parts per 10,000; the Osborne, Stimson, Fiock and Ginnings' and the authors' results to roughly 2 parts per 10,000.

A comparison of the three independent investigations on the basis of the differences of temperature corresponding to the pressure differences proves interesting. The data can be readily computed from the values of dp/dT and it is found that Δt_m , the arithmetic mean of the differences, for the Egerton and Callendar results relative to the authors' observed results is 0.01675°C . The similar difference in the case of the authors' observed pressures and those of Osborne, Stimson, Fiock and Ginnings is 0.00973°C . The mean of the temperature differences for the smoothed or computed pressures given by the two American groups of investigators is 0.00823°C . Figure 1 has been prepared by referring the experimental results of the present work, of the Reichsanstalt, of Egerton and Callendar, and of Osborne, Stimson, Fiock and Ginnings to the vapor pressures as computed from Equation 1. A line representing the smoothed values computed by the two equations used by Osborne, Stimson, Fiock and Ginnings is also included. It will be observed that the great bulk of all observations lie within a range of pressure corresponding to $\pm 0.02^\circ \text{C}$.

Table 5 gives the pressures for each degree centigrade from 100° to 374° computed by means of equation 1.

THE CRITICAL TEMPERATURE AND CRITICAL PRESSURE.

It will be observed that formula 1 contains the critical pressure and the critical temperature. The value for the former quantity 218.167 Int. Atm. was obtained through a graphical investigation of the relation between pressure and temperature in the critical region using 374.11°C as the critical temperature. The latter value was selected on the basis of observations of pressure and volumnometer settings (the latter are proportional to the volumes of water in the container)

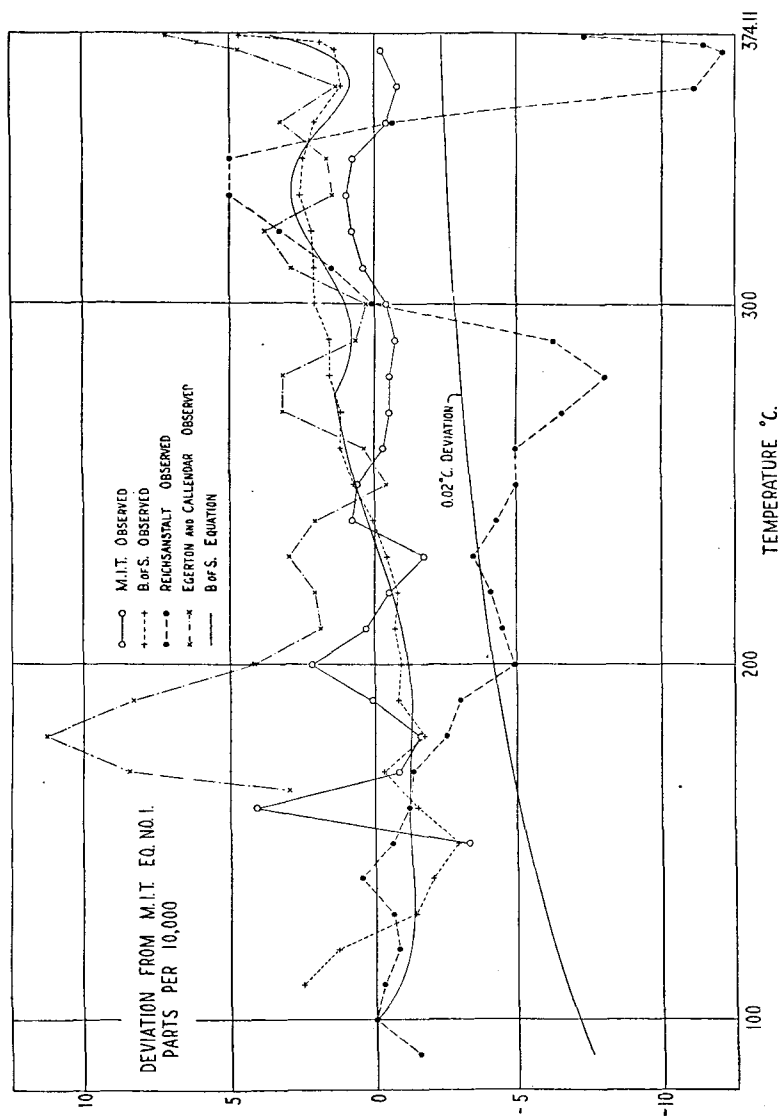


FIGURE 1.

along isothermals below and above 374. The graph of the data is identical with the figure 3 (p. 966) of L. Holborn and A. Baumann's¹⁵ paper of 1910 which lead to the selection of 374° C as the critical temperature.*

Our isotherms are remarkably similar to the isotherms obtained by the authors of the above paper, but we are led to conclude that the critical isotherm is slightly higher, 374.11° C. We doubt that the latter value is exact to better than 0.1° because of insensitiveness inherent in the method. The true value may be slightly higher than the latter temperature but our experience to date indicates that it is certainly not lower. The critical values 218.167 Int. atm. and 374.11° C may be regarded as consistent but probably not final.

The choice of a formula relating the pressure to the temperature wherein a certain pressure and temperature, $p_c = 218.167$ and $t_c = 374.11$, enter in such a manner that all lower values of the saturation pressure and temperature must lie on a curve passing through p_c , t_c may be undesirable. However, no distortion of the values below p_c and t_c will result if p_c and t_c are really consistent with the lower values or lie on a smooth curve with the latter. Pains were accordingly taken to determine p_c with care by graphical means using all available data below the selected temperature 374.11°. The constant p_c could of course have been left to play the role of an undetermined constant but the additional labor involved in carrying out the least square computation did not appear warranted until additional information relative to the critical temperature becomes available.

THE CHANGE OF PRESSURE WITH TEMPERATURE.

Exact values of dp/dT are of great importance in making computations involving comparisons between measured quantities and similar quantities based on deduction from the two principles of thermodynamics. The derivative may be obtained by differentiation of the smoothing function, or the pressures, smoothed by the method of adjusted differences, may be submitted to computation, as for example by the very convenient method of Professor George Rutledge.⁶ In Table 4, as already stated, the values in the next to the last column have been computed by the equation resulting from the differentiation

¹⁵ L. Holborn and A. Baumann, *Ann. der Phys.* 31, 945 (1910).

* The normal sulphur boiling point was taken at 445° C by Holborn and Baumann. Using 444.6° C the critical temperature would be about 0.3° lower or 373.7° C.

of equation 1. The values in the adjacent column are similar values computed by Osborne, Stimson, Fioch and Ginnings from their smoothing equation. The accord between the two sets of derivatives is excellent to 360° when consideration is given to the considerable difference in the forms of the smoothing function used in computing the values.

At 360° the difference between the two computed derivatives amounts to 2.9 parts per 10,000 but the difference at 370° has changed sign and amounts to 27 parts per 10,000 while at 374° the difference has grown to 50 parts per 10,000. In Fig. 2 a graphical representation is

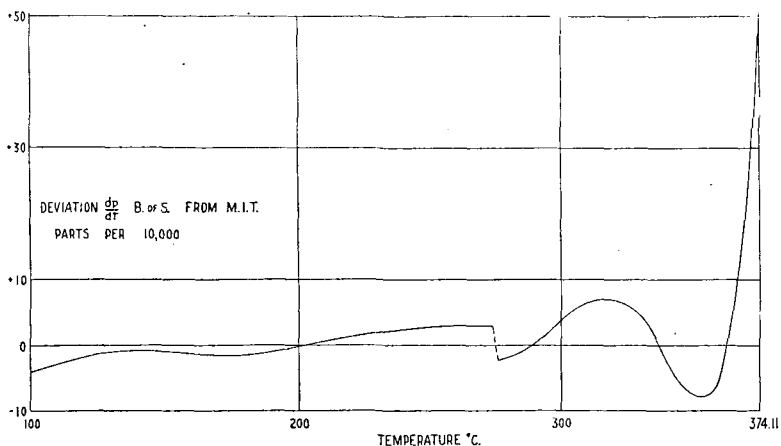


FIGURE 2.

given wherein the values of dp/dT from the U. S. Bureau of Standards equations is related to the derivatives computed from the differentiated Equation 1. The break in the curve occurs at the temperature where a shift is made from the low pressure equation of Osborne, Stimson, Fioch and Ginnings to the high pressure equation.

Table 6 gives the values of dp/dT for each degree centigrade from 100° to 374° computed by means of the differentiated equation based on equation 1.

THE SATURATION PRESSURES BELOW 100° C.

The experimental values of the vapor pressure of water below 100° are not believed to be in need of revision. Thus if vapor pressures are computed by means of equation (1) at 90, 80, 70, 60, 50 degrees, it will

be found that values result which are in excellent agreement with the values given in the Reichsanstalt Wärmetabellen edition of 1916. Moreover using the data in the latter table for each 10° from 10° to 100° for determining the constants of equation 2 by least square computation, it is found that the value of the pressures computed at 110, 120, 130, 140, 150 degrees are in excellent accord with the Reichsanstalt measurements at these temperatures and also the recent results by Osborne, Stimson, Fioch and Ginnings. In a word the values from 10° to 90° are entirely consistent with the new measurements above 100° and may be accepted with confidence. Table 7 gives the pressures for each five degrees, computed by equation (2), by equation (1) and derivatives computed by the respective smoothing equations.

Vapor Pressure Equation for Water 10° to 150° C.

$$\log_{10} \frac{p_c}{p} = \frac{x}{T} \left[\frac{a + bx + cx^3}{1 + dx} \right] \quad (2)$$

$$\log p_c = 2.3387890 \text{ for atm.}$$

$$= 5.2196026 \text{ for mm.}$$

$$a = 3.2437814$$

$$b = 5.86826 \times 10^{-3}$$

$$c = 1.1702379 \times 10^{-8}$$

$$d = 2.1878462 \times 10^{-3}$$

The computed value of the pressure at zero degrees (4.5893 mm.) differs considerably from the "observed" value (4.579 mm.). In fact, the same value (4.579 mm.) at zero degrees is given for both ice and water in the Wärmetabellen. But this is impossible for the normal triple point of water is known to be 0.010°. The value measured at zero degrees was certainly 4.579 mm. as attested to by two separate investigations, but it must correspond either to sub-cooled liquid water or to ice. We believe it to be probably the vapor pressure of sub-cooled water at zero degrees.

The computed pressures in Table 7 accord closely with the observed pressures except at 5° and 0°. The pressures are of course becoming so small that a precision of measurement of even 0.001 mm. amounts to 2 parts per 10,000 at 0° but the difference between the observed and computed values (Equation 2) is 22 parts per 10,000; a difference far outside the precision attained by K. Scheel and W. Heuse.¹⁶ The only evident conclusion is that formula 2 is insufficient to give precise

¹⁶ K. Scheel and W. Heuse, *Ann. d. Phys.* 31, 715 (1910).

values of pressure below 10° notwithstanding the fidelity with which the formula reproduces the pressures above 10° . Figure 3 gives the differences in parts per ten thousand between the computed (formula 2) and measured values of the pressure.

In the report on the steam research for December 1929 several smoothing formulas were given for the range of vapor pressures from the ice point to the critical pressure.¹⁷ Equation (5) reproduces the

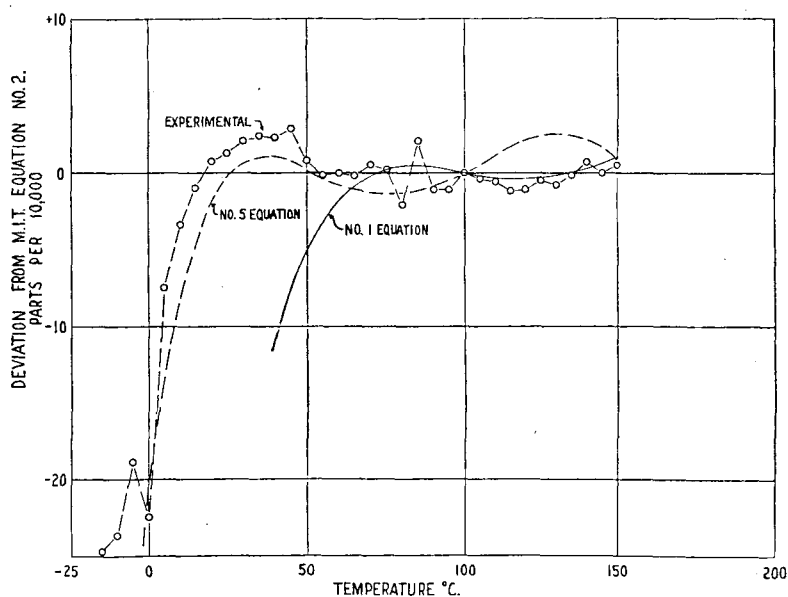


FIGURE 3.

experimental values from zero degrees to 100° with fidelity and is much superior to equation (2) for the range 0 to 10° . The equation is as follows:

$$\log_{10} p = 2.3395111 - \frac{1}{T}(a_0 x + Y \cdot x^2) \quad (5)$$

$$x = 374.11 - t; \quad a_0 = 3.4763; \quad T = 273.13 + t^{\circ}\text{C}.$$

$$10^3 \cdot Y = -4.494947 + 2.000419 \cdot 10^{-2}x - 3.593284 \times 10^{-5}x^2 + 3.143572 \cdot 10^{-8}x^3.$$

¹⁷ Mech. Eng. 52, 125 (1930).

The derivative at 0° computed from the differentiated equation based on (5) is 0.00043816 I. A. as compared with 0.00043806 deduced from the differentiated equation (2). The pressures at 0° are for (5) 4.5798 mm. and for (2) 4.5893 mm. while the experimental value is 4.5790.

THE NORMAL BOILING TEMPERATURE OF WATER.

The most satisfactory mode of using water to establish the 100° reference temperature is undoubtedly to boil the substance in an apparatus whereby the pressure can be kept constantly at 76 cm. The apparatus for the purpose is, however, expensive and exists in few laboratories at present. The common practice of conducting the calibration of thermometers by boiling at the prevailing atmospheric pressure requires a knowledge of the dependence of the boiling temperature upon the pressure. Using Equations (1) and (2) the following formula has been devised, valid from 96° to 103° , whereby suitable corrections can be computed to reduce the observations on the boiling temperature of water at any pressure p to the normal at 760 mm. The pressure p entering the formula implicitly must be corrected to standard gravity 980.665 dynes and the usual corrections for temperature applied to the barometer. The formula follows:

$$\Delta t = 0.0368535\Delta p - 2.0084 \times 10^{-5}\Delta p^2 + 1.714 \times 10^{-8}\Delta p^3$$

$$\Delta p = (p_{\text{corr. bar.}} - 760) \text{ mm.}$$

TABLE 8.

Δt	Δp	Δt_{calc}
-4	-102.310	-3.99906
-3	-77.873	-2.99978
-2	-52.688	-2.00000
-1	-26.736	-1.00000
0	0	0.00000
+1	27.538	1.00000
+2	55.897	2.00024
+3	85.095	3.00118

The Table 8 indicates that the formula which is consistent with the best present knowledge of the properties of water based on the International Temperature Scale is reliable to better than 0.001° C for several degrees above and below the fixed point 100° .

The authors acknowledge with much pleasure the coöperation of Dr. Robert S. Taylor, who contributed effectively in the work of assembling and perfecting the functioning of the steam apparatus during the early stages of the investigation.

TABLE 1.
Series I—SATURATION PRESSURES OF WATER IN INT. ATM.

Date	Container	Temp. °C.		Press. (Int. Atm.)		
7/15/29	No. 2	150	4 BS		4.705	
				p_{calc}	4.6983	$\Delta t + 0.053^\circ$
12/30/24	No. 1	160	1		6.103	
1/29/25	No. 1	160	1		6.097	
1/29/25	No. 1	160	1		6.098	
11/4/29	No. 2	160	4 BS		6.095	
7/15/29	No. 2	160	4 BS		6.122	
				p_{mean}	6.1030	
				p_{calc}	6.1007	$\Delta t + 0.015^\circ$
1/2/25	No. 1	170	1		7.834	
1/2/25	No. 1	170	1		7.817	
1/20/25	No. 1	170	1		7.813	
11/4/29	No. 2	170	4 BS		7.807	
7/12/29	No. 2	170	4 BS		7.817	
7/13/29	No. 2	170	4 BS		7.830	
7/15/29	No. 2	170	4 BS		7.823	
				p_{mean}	7.8201	
				p_{calc}	7.8180	$\Delta t + 0.011^\circ$
1/21/25	No. 1	180	1		9.890	
1/21/25	No. 1	180	1		9.908	
11/4/29	No. 2	180	4 BS		9.877	
7/12/29	No. 2	180	4 BS		9.900	
				p_{mean}	9.8938	
				p_{calc}	9.8975	$\Delta t - 0.016^\circ$
1/27/25	No. 1	190	1		12.374	
1/27/25	No. 1	190	1		12.377	
10/14/29	No. 2	190	4 BS		12.385	
11/4/29	No. 2	190	4 BS		12.373	
7/11/29	No. 2	190	4 BS		12.387	
7/12/29	No. 2	190	4 BS		12.395	
				p_{mean}	12.3818	
				p_{calc}	12.3897	$\Delta t - 0.029^\circ$
1/28/25	No. 1	200	1		15.331	
4/18/25	No. 1	200	1		15.337	
4/21/25	No. 1	200	1		15.351	
4/21/25	No. 1	200	1		15.321	

TABLE 1—*Continued*

Date	Container	Temp. °C.		Press. (Int. Atm.)	
4/21/25	No. 1	200	1	15.341	
4/22/25	No. 1	200	1	15.344	
5/7/25	No. 1	200	1	15.324	
5/7/25	No. 1	200	1	15.356	
5/8/25	No. 1	200	1	15.343	
5/8/25	No. 1	200	1	15.327	
5/8/25	No. 1	200	1	15.343	
5/11/25	No. 1	200	1	15.316	
10/14/29	No. 2	200	4 BS	15.360	
7/11/29	No. 2	200	4 BS	15.353	
				p_{mean}	15.3391
				p_{calc}	15.3486 Δt -0.030°
4/23/25	No. 1	210	1	18.816	
4/23/25	No. 1	210	1	18.816	
4/23/25	No. 1	210	1	18.823	
10/18/29	No. 2	210	4 BS	18.820	
7/11/29	No. 2	210	4 BS	18.834	
				p_{mean}	18.8218
				p_{calc}	18.8314 Δt -0.025°
4/23/25	No. 1	220	1	22.890	
4/24/25	No. 1	220	1	22.887	
4/24/25	No. 1	220	1	22.892	
7/11/29	No. 2	220	4 BS	22.898	
8/16/29	No. 2	220	4 BS	22.895	
				p_{mean}	22.8924
				p_{calc}	22.8983 Δt 0.013°
4/24/25	No. 1	230	1	27.587	
4/25/25	No. 1	230	1	27.587	
4/25/25	No. 1	230	1	27.597	
7/10/29	No. 2	230	4 BS	27.611	
7/11/29	No. 2	230	4 BS	27.616	
				p_{mean}	27.5996
				p_{calc}	27.6127 Δt -0.026°
4/27/25	No. 1	240	1	33.002	
4/27/25	No. 1	240	1	33.009	
4/27/25	No. 1	240	1	33.008	
7/9/29	No. 2	240	4 BS	33.021	
7/10/29	No. 2	240	4 BS	32.989	

TABLE 1—*Continued*

Date	Container	Temp. °C.		Press. (Int. Atm.)	
7/16/29	No. 2	240	4 BS	32.997	
7/17/29	No. 2	240	4 BS	33.031	
7/23/29	No. 2	240	4 BS	33.035	
				p_{mean}	33.0115
				p_{calc}	33.0412 Δt -0.051°
4/28/25	No. 1	250	1	39.228	
4/28/25	No. 1	250	1	39.230	
4/28/25	No. 1	250	1	29.233	
1/29/30	No. 2	250	4 BS	39.228	
1/29/30	No. 2	250	4 BS	39.232	
				p_{mean}	39.2302
				p_{calc}	39.2536 Δt -0.035°
4/29/25	No. 1	260	1	46.309	
4/29/25	No. 1	260	1	46.313	
2/1/30	No. 2	260	4 BS	46.292	
2/2/30	No. 2	260	4 BS	46.279	
4/29/25	No. 1	260	1	46.303	
				p_{mean}	46.2992
				p_{calc}	46.3232 Δt -0.032°
4/29/25	No. 1	270	1	54.305	
4/30/25	No. 1	270	1	54.315	
4/29/25	No. 1	270	1	54.317	
				p_{mean}	54.3123
				p_{calc}	54.3269 Δt -0.017°
4/30/25	No. 1	280	1	63.314	
5/1/25	No. 1	280	1	63.296	
5/1/25	No. 1	280	1	63.326	
				p_{mean}	63.3120
				p_{calc}	63.3459 Δt -0.035°
5/4/25	No. 1	290	1	73.439	
5/4/25	No. 1	290	1	73.425	
5/4/25	No. 1	290	1	73.424	
				p_{mean}	73.4293
				p_{calc}	73.4661 Δt -0.034°
7/9/25	No. 1	300	2	84.792	
7/9/25	No. 1	300	2	84.818	

TABLE 1—*Continued*

Date	Container	Temp. °C.		Press. (Int. Atm.)	
7/9/25	No. 1	300	2	84.803	
9/2/25	No. 1	300	2	84.788	
9/2/25	No. 1	300	2	84.791	
				p_{mean}	84.7984
				p_{calc}	84.7794 $\Delta t + 0.016^\circ$
9/8/25	No. 1	310	2	97.407	
9/8/25	No. 1	310	2	97.416	
9/8/25	No. 1	310	2	97.420	
2/25/28	No. 1	310	4 BS	97.446	
2/27/28	No. 1	310	4 BS	97.450	
6/1/28	No. 1	310	4 BS	97.426	
				p_{mean}	97.4275
				p_{calc}	97.3854 $\Delta t + 0.032^\circ$
7/13/25	No. 1	320	2	111.577	
7/13/25	No. 1	320	2	111.566	
7/13/25	No. 1	320	2	111.303	
9/10/25	No. 1	320	2	111.450	
9/10/25	No. 1	320	2	111.446	
9/10/25	No. 1	320	2	111.448	
2/27/28	No. 1	320	4 BS	111.467	
				p_{mean}	111.4653
				p_{calc}	111.3934 $\Delta t + 0.049^\circ$
2/28/28	No. 1	330	4 BS	126.975	
2/28/28	No. 1	330	4 BS	127.000	
4/5/28	No. 1	330	4 BS	127.010	
				p_{mean}	126.9950
				p_{calc}	126.9265 $\Delta t + 0.042^\circ$
7/15/25	No. 1	340	2	144.382	
7/15/25	No. 1	340	2	144.383	
7/15/25	No. 1	340	2	144.373	
9/18/25	No. 1	340	2	144.296	
9/18/25	No. 1	340	2	144.298	
10/21/26	No. 1	340	4 BS	144.312	
10/21/26	No. 1	340	4 BS	144.333	
2/28/28	No. 1	340	4 BS	144.191	
				p_{mean}	144.3210
				p_{calc}	144.1278 $\Delta t + 0.107^\circ$

TABLE 1—*Continued*

Date	Container	Temp. °C.		Press. (Int. Atm.)
6/9/26	No. 1	350	4 BS	163.357
6/9/26	No. 1	350	4 BS	163.356
6/9/26	No. 1	350	4 BS	163.366
6/9/26	No. 1	350	4 BS	163.373
6/30/26	No. 1	350	4 BS	163.322
6/30/26	No. 1	350	4 BS	163.327
6/30/26	No. 1	350	4 BS	163.329
10/20/26	No. 1	350	4 BS	163.381
10/20/26	No. 1	350	4 BS	163.383
10/20/26	No. 1	350	4 BS	163.414
10/20/26	No. 1	350	4 BS	163.213
				p_{mean} 163.3474
				p_{calc} 163.1704 $\Delta t + 0.088^\circ$
9/23/25	No. 1	355	2	173.638
9/23/25	No. 1	355	2	173.643
				p_{mean} 173.6405
				p_{calc} 173.4485 $\Delta t + 0.091^\circ$
6/11/26	No. 1	360	4 BS	184.469
6/11/26	No. 1	360	4 BS	184.478
6/11/26	No. 1	360	4 BS	184.498
6/29/26	No. 1	360	4 BS	184.446
6/29/26	No. 1	360	4 BS	184.447
10/21/26	No. 1	360	4 BS	184.387
10/21/26	No. 1	360	4 BS	184.410
10/21/26	No. 1	360	4 BS	184.411
4/5/27	No. 1	360	4 BS	184.362
4/5/27	No. 1	360	4 BS	184.355
				p_{mean} 184.4263
				p_{calc} 184.2744 $\Delta t + 0.068^\circ$
6/14/26	No. 1	365	4 BS	195.763
6/14/26	No. 1	365	4 BS	195.829
				p_{mean} 195.7960
				p_{calc} 195.6895 $\Delta t + 0.045^\circ$
6/15/26	No. 1	370	4 BS	207.855
6/15/26	No. 1	370	4 BS	207.845
6/16/26	No. 1	370	4 BS	207.924
				p_{mean} 207.8747
				p_{calc} 207.7414 $\Delta t + 0.054^\circ$

TABLE 1—*Continued*

Date	Container	Temp. °C.	Press. (Int. Atm.)
6/21/26	No. 1	371 4 BS	210.361
6/21/26	No. 1	371 4 BS	210.353
6/21/26	No. 1	371 4 BS	210.346
6/21/26	No. 1	371 4 BS	210.343
6/22/26	No. 1	371 4 BS	210.350
			p_{mean} 210.3506
			p_{calc} 210.2332 $\Delta t + 0.047^\circ$
6/23/26	No. 1	372 4 BS	212.878
6/23/26	No. 1	372 4 BS	212.884
6/23/26	No. 1	372 4 BS	212.886
			p_{mean} 212.8827
			p_{calc} 212.7535 $\Delta t + 0.051^\circ$
6/25/26	No. 1	373 4 BS	215.491
6/25/26	No. 1	373 4 BS	215.479
6/25/26	No. 1	373 4 BS	215.529
			p_{mean} 215.4997
			p_{calc} 215.3027 $\Delta t + 0.077^\circ$
6/28/26	No. 1	374 4 BS	218.191
6/28/26	No. 1	374 4 BS	218.211
6/28/26	No. 1	374 4 BS	218.191
7/9/26	No. 1	374 4 BS	218.142
7/9/26	No. 1	374 4 BS	218.170
7/9/26	No. 1	374 4 BS	218.209
7/10/26	No. 1	374 4 BS	218.165
7/10/26	No. 1	374 4 BS	218.243
7/10/26	No. 1	374 4 BS	218.236
			p_{mean} 218.1953
			p_{calc} 217.8815 $\Delta t + 0.121^\circ$

TABLE 2.

Series II—SATURATION PRESSURES OF WATER IN INT. ATM.

Date	Container	Temp. °C.	Press. (Int. Atm.)
5/11/32	No. 1 B	200 4 BS	15.340
5/11/32	No. 1 B	200 4 BS	15.339
5/12/32	No. 1 B	200 4 BS	15.340
5/13/32	No. 1 B	200 4 BS	15.338
5/13/32	No. 1 B	200 4 BS	15.342
			p_{mean} 15.3398
			p_{calc} 15.3486 $\Delta t - 0.027^\circ$

TABLE 2—Continued

Date	Container	Temp. °C.		Press. (Int. Atm.)	
5/13/32	No. 1 B	260	4 BS	46.316	
5/16/32	No. 1 B	260	4 BS	46.312	
5/16/32	No. 1 B	260	4 BS	46.316	
				p_{mean}	46.3147
				p_{calc}	46.3232 Δt -0.011°
5/16/32	No. 1 B	280	4 BS	63.330	
				p_{calc}	63.3459 Δt -0.017°
5/16/32	No. 1 B	300	4 BS	84.767	
5/17/32	No. 1 B	300	4 BS	84.765	
				p_{mean}	84.7660
				p_{calc}	84.7794 Δt -0.011°
5/17/32	No. 1 B	310	4 BS	97.395	
				p_{calc}	97.3854 Δt +0.007°
5/17/32	No. 1 B	320	4 BS	111.402	
				p_{calc}	111.3934 Δt +0.006°
5/17/32	No. 1 B	330	4 BS	126.938	
				p_{calc}	126.9265 Δt +0.007°
5/18/32	No. 1 B	340	4 BS	144.146	
5/18/32	No. 1 B	340	4 BS	144.145	
				p_{mean}	144.1455
				p_{calc}	144.1278 Δt +0.010°
5/18/32	No. 1 B	350	4 BS	163.165	
				p_{calc}	163.1704 Δt -0.003°
5/18/32	No. 1 B	360	4 BS	184.262	
				p_{calc}	184.2744 Δt -0.006°
5/18/32	No. 1 B	370	4 BS	207.757	
5/18/32	No. 1 B	370	4 BS	207.747	
				p_{mean}	207.7520
				p_{calc}	207.7414 Δt +0.004°

TABLE 3.

Series III—SATURATION PRESSURES OF WATER IN INT. ATM.

Date	Container	Temp. °C.		Press. (Int. Atm.)	
7/30/32	No. 3 B	150	4 BS	4.6966	
8/1/32	No. 3 B	150	4 BS	4.6968	
				p_{mean}	4.6967
				p_{calc}	4.6983 $\Delta t -0.013^\circ$
7/30/32	No. 3 B	160	4 BS	6.1021	
8/1/32	No. 3 B	160	4 BS	6.1038	
8/2/32	No. 3 B	160	4 BS	6.1038	
				p_{mean}	6.1032
				p_{calc}	6.1007 $\Delta t +0.016^\circ$
7/29/32	No. 3 B	170	4 BS	7.8170	
7/30/32	No. 3 B	170	4 BS	7.8182	
8/2/32	No. 3 B	170	4 BS	7.8169	
				p_{mean}	7.8174
				p_{calc}	7.8180 $\Delta t -0.003^\circ$
7/29/32	No. 3 B	180	4 BS	9.8953	
8/1/32	No. 3 B	180	4 BS	9.8979	
8/1/32	No. 3 B	180	4 BS	9.8945	
				p_{mean}	9.8959
				p_{calc}	9.8975 $\Delta t -0.007^\circ$
7/29/32	No. 3 B	190	4 BS	12.3887	
8/1/32	No. 3 B	190	4 BS	12.3909	
				p_{mean}	12.3898
				p_{calc}	12.3897 $\Delta t 0.000^\circ$
7/11/32	No. 3 B	200	4 BS	15.365	
7/14/32	No. 3 B	200	4 BS	15.352	
7/14/32	No. 3 B	200	4 BS	15.355	
7/14/32	No. 3 B	200	4 BS	15.354	
7/18/32	No. 3 B	200	4 BS	15.352	
7/26/32	No. 3 B	200	4 BS	15.351	
7/27/32	No. 3 B	200	4 BS	15.353	
7/29/32	No. 3 B	200	4 BS	15.3484	
				p_{mean}	15.3538
				p_{calc}	15.3486 $\Delta t +0.016^\circ$
7/18/32	No. 3 B	210	4 BS	18.834	

TABLE 3—*Continued*

Date	Container	Temp. °C.		Press. (Int. Atm.)	
7/26/32	No. 3 B	210	4 BS	18.829	
				p_{mean} 18.8315	
				p_{calc} 18.8314	Δt 0.000°
7/18/32	No. 3 B	220	4 BS	22.902	
7/26/32	No. 3 B	220	4 BS	22.892	
				p_{mean} 22.8970	
				p_{calc} 22.8983	Δt -0.003°
7/26/32	No. 3 B	230	4 BS	27.608	
				p_{calc} 27.6117	Δt -0.007°
7/18/32	No. 3 B	240	4 BS	33.059	
7/19/32	No. 3 B	240	4 BS	33.040	
7/26/32	No. 3 B	240	4 BS	33.035	
				p_{mean} 33.0447	
				p_{calc} 33.0412	Δt +0.006°
7/19/32	No. 3 B	250	4 BS	39.256	
7/26/32	No. 3 B	250	4 BS	39.255	
				p_{mean} 39.2555	
				p_{calc} 39.2536	Δt +0.003°
7/19/32	No. 3 B	260	4 BS	46.323	
7/25/32	No. 3 B	260	4 BS	46.329	
				p_{mean} 46.3260	
				p_{calc} 46.3232	Δt +0.004°
7/19/32	No. 3 B	270	4 BS	54.321	
7/25/32	No. 3 B	270	4 BS	54.327	
				p_{mean} 54.3240	
				p_{calc} 54.3269	Δt -0.003°
7/19/32	No. 3 B	280	4 BS	63.344	
7/25/32	No. 3 B	280	4 BS	63.354	
				p_{mean} 63.3490	
				p_{calc} 63.3459	Δt +0.003°
7/20/32	No. 3 B	290	4 BS	73.455	
7/25/32	No. 3 B	290	4 BS	73.467	
				p_{mean} 73.4610	
				p_{calc} 73.4661	Δt -0.005°

TABLE 3—Continued

Date	Container	Temp. °C.	Press. (Int. Atm.)
7/20/32	No. 3 B	300 4 BS	84.779
7/25/32	No. 3 B	300 4 BS	84.783
			p_{mean} 84.7810
			p_{calc} 84.7794 Δt +0.001°
7/20/32	No. 3 B	310 4 BS	97.381
7/25/32	No. 3 B	310 4 BS	97.391
			p_{mean} 97.3860
			p_{calc} 97.3854 Δt 0.000°
7/20/32	No. 3 B	320 4 BS	111.402
7/25/32	No. 3 B	320 4 BS	111.401
			p_{mean} 111.4015
			p_{calc} 111.3934 Δt +0.005°
7/20/32	No. 3 B	330 4 BS	126.934
7/23/32	No. 3 B	330 4 BS	126.946
			p_{mean} 126.9400
			p_{calc} 126.9265 Δt +0.008°
7/20/32	No. 3 B	340 4 BS	144.131
7/23/32	No. 3 B	340 4 BS	144.142
			p_{mean} 144.1365
			p_{calc} 144.1278 Δt +0.005°
7/21/32	No. 3 B	350 4 BS	163.159
7/22/32	No. 3 B	350 4 BS	163.168
			p_{mean} 163.1635
			p_{calc} 163.1704 Δt -0.003°
7/21/32	No. 3 B	360 4 BS	184.254
7/22/32	No. 3 B	360 4 BS	184.263
			p_{mean} 184.2585
			p_{calc} 184.2744 Δt -0.007°
7/22/32	No. 3 B	370 4 BS	207.721
			p_{calc} 207.7414 Δt -0.008°

TABLE 4

COMPARISON OF VAPOR PRESSURE MEASUREMENTS

M. I. T. Equation $\log \frac{p_c}{p} = \frac{x}{T} \left[\frac{a + bx + cx^3 + ex^4}{1 + dx} \right]$

$p_c = 218.167 \text{ atm. Int.}$ $\log p_c = 2.3387890$ $x = t_c - t$ $t_c = 374.11$

$T = t + 273.16$ $a = 3.3463130$ $b = .0414113$ $c = .007515484 \times 10^{-6}$

$d = .013794481$ $e = .00656444 \times 10^{-8}$

t° C.	Mean Observed p M. I. T.	Calculated p M. I. T.	Mean Observed p B. S.	Calculated p B. S.	Egerton & Callendar Obs. p
100		1.000000			
110	1.4139*	1.41395	1.4143	1.4138	
120	1.9595*	1.95954	1.9598	1.9593	
130	2.6662*	2.66616	2.6658	2.6658	
140	3.5669*	3.56683	3.5661	3.5664	
150	4.6967	4.69826	4.6969	4.6977	
160	6.1032	6.10071	6.0998	6.1000	
170	7.8174	7.81802	7.8178	7.8171	
180	9.8959	9.89745	9.8958	9.8962	7.8246
190	12.3898	12.3897	12.3887	12.3881	9.9086
200	15.352	15.3486	15.3472	15.3468	12.400
210	18.832	18.8314	18.8300	18.8296	15.355
220	22.897	22.8983	22.8964	22.8969	18.835
230	27.608	27.6127	27.6117	27.6122	22.903
240	33.044	33.0412	33.0416	33.0421	27.621
250	39.256	39.2536	39.2566	39.2563	33.048
260	46.322	46.3232	46.3286	46.3280	39.252
270	54.324	54.3269	54.3333	54.3339	46.325
280	63.343	63.3459	63.3558	63.3524	54.345
290	73.461	73.4661	73.4779	73.4723	63.366
300	84.776	84.7794	84.7969	84.7881	73.471
310	97.389	97.3854	97.4062	97.4015	84.782
320	111.402	111.3934	111.418	111.420	97.414
330	126.939	126.9265	126.960	126.964	111.436
340	144.139	144.1278	144.167	144.168	126.946
350	163.164	163.1704	163.205	163.200	144.152
360	184.260	184.2744	184.297	184.290	163.224
370	207.737	207.7414	207.771	207.781	184.299
372		212.7535	212.795	212.808	207.839
374		217.8815	217.985	217.958	212.883
374.11	218.167				218.048

* I. C. T. Value used for M. I. T. Obs.

TABLE 4—Continued

$t^{\circ}\text{C.}$	Obs. p M. I. T. —Cal. p M. I. T.	Obs. p B. S. —Cal. p B. S.	Obs. p B. S. —Obs. p M. I. T.	Cal. p B. S. —Cal. p M. I. T.	Obs. p E. & C. —Obs. p M. I. T.	$\frac{dp}{dT}$ M. I. T.	$\frac{dp}{dT}$ B. S.
100						.035703	.03569
110	— .00005*	+ .0005	+ .0004*	— .00015		.047517	.04750
120	— .00004*	+ .0005	+ .0003*	— .00024		.062090	.06208
130	+ .00004*	.0000	— .0004*	— .00036		.079784	.07978
140	+ .00007*	— .0003	— .0008*	— .00043		.100964	.10095
150	— .00156	— .0008	+ .0002	— .00056		.125993	.12598
160	+ .00249	— .0002	— .0034	— .00071		.155228	.15521
170	— .00062	+ .0007	+ .0004	— .00092	+ .0072	.189021	.18899
180	— .00155	— .0004	— .0001	— .00125	+ .0127	.227711	.22768
190	+ .0001	+ .0006	— .0011	— .0016	+ .0102	.271632	.27161
200	+ .0034	+ .0004	— .0048	— .0018	+ .003	.321106	.32110
210	+ .0006	+ .0004	— .0020	— .0018	+ .003	.37645	.37647
220	— .0013	— .0005	— .0006	— .0014	+ .006	.43798	.43805
230	— .0047	— .0005	+ .0037	— .0005	+ .013	.50601	.5061
240	+ .0028	— .0005	— .0024	+ .0009	+ .004	.58086	.5810
250	+ .0024	+ .0003	+ .0006	+ .0027	— .004	.66285	.6630
260	— .0012	+ .0006	+ .0066	+ .0048	+ .003	.75235	.7524
270	— .0029	— .0006	+ .0093	+ .0070	+ .021	.84974	.8496
280	— .0029	+ .0034	+ .0128	+ .0065	+ .023	.95548	.9553
290	— .0051	+ .0056	+ .0169	+ .0062	+ .010	1.07009	1.0701
300	— .0034	+ .0088	+ .0209	+ .0087	+ .006	1.19424	1.1947
310	+ .0036	+ .0047	+ .0172	+ .0161	+ .025	1.32878	1.3297
320	+ .0086	— .002	+ .016	+ .0266	+ .034	1.47486	1.4760
330	+ .0125	— .004	+ .021	+ .0375	+ .007	1.63413	1.6349
340	+ .0112	— .001	+ .028	+ .0402	+ .013	1.80899	1.8086
350	— .0064	+ .005	+ .041	+ .0296	+ .064	2.00315	2.0016
360	— .0144	+ .007	+ .037	+ .0156	+ .039	2.22264	2.2220
370	— .0077	— .010	+ .034	+ .0396	+ .102	2.47786	2.4846
372		— .013		+ .0545		2.53463	2.5542
374		+ .027		+ .0767		2.59376	2.6068
374.11							

E. & C. = Egerton & Callendar

TABLE 5.
Vapor Pressure of Water Computed by Means of Equation 1.

	0	1	2	3	4	5	6	7	8	9
100	1.0000	1.0362	1.0735	1.1119	1.1515	1.1922	1.2341	1.2772	1.3215	1.3671
110	1.4139	1.4621	1.5116	1.5625	1.6148	1.6685	1.7237	1.7804	1.8385	1.8982
120	1.9595	2.0224	2.0870	2.1532	2.2211	2.2907	2.3621	2.4354	2.5104	2.5873
130	2.6662	2.7469	2.8296	2.9144	3.0012	3.0900	3.1810	3.2741	3.3695	3.4670
140	3.5668	3.6690	3.7734	3.8803	3.9895	4.1013	4.2155	4.3323	4.4516	4.5736
150	4.6983	4.8256	4.9557	5.0886	5.2243	5.3629	5.5045	5.6490	5.7965	5.9470
160	6.1007	6.2575	6.4175	6.5808	6.7473	6.9171	7.0904	7.2670	7.4471	7.6308
170	7.8180	8.0088	8.2034	8.4016	8.6036	8.8094	9.0190	9.2326	9.4502	9.6718
180	9.8974	10.127	10.361	10.599	10.842	11.089	11.340	11.595	11.856	12.120
190	12.390	12.663	12.942	13.226	13.514	13.807	14.105	14.409	14.717	15.030
200	15.349	15.672	16.002	16.336	16.675	17.021	17.372	17.728	18.090	18.458
210	18.831	19.211	19.596	19.987	20.384	20.788	21.197	21.613	22.035	22.463
220	22.898	23.339	23.787	24.242	24.703	25.170	25.645	26.126	26.615	27.110
230	27.613	28.122	28.639	29.163	29.695	30.233	30.780	31.334	31.895	32.464
240	33.041	33.626	34.219	34.819	35.428	36.045	36.670	37.303	37.945	38.595
250	39.254	39.921	40.597	41.281	41.974	42.677	43.388	44.108	44.837	45.575
260	46.323	47.080	47.847	48.623	49.408	50.203	51.008	51.823	52.648	53.482
270	54.327	55.182	56.047	56.922	57.808	58.704	59.611	60.529	61.457	62.396
280	63.346	64.307	65.279	66.262	67.257	68.263	69.280	70.309	71.350	72.402
290	73.466	74.542	75.630	76.730	77.843	78.968	80.105	81.254	82.417	83.592
300	84.779	85.980	87.194	88.421	89.661	90.914	92.181	93.462	94.756	96.064
310	97.385	98.721	100.07	101.43	102.81	104.21	105.61	107.04	108.47	109.93
320	111.39	112.88	114.37	115.89	117.42	118.96	120.52	122.10	123.69	125.30
330	126.93	128.57	130.23	131.90	133.60	135.31	137.04	138.78	140.55	142.33
340	144.13	145.95	147.78	149.64	151.51	153.41	155.32	157.25	159.20	161.18
350	163.17	165.18	167.22	169.27	171.35	173.45	175.57	177.71	179.88	182.06
360	184.27	186.51	188.77	191.05	193.36	195.69	198.05	200.43	202.84	205.28
370	207.74	210.23	212.75	215.30	217.88					

TABLE 6.
Values of dp/dt for Saturated Water Vapor derived from Equation 1.

	0	1	2	3	4	5	6	7	8	9
100	0.035703	0.036770	0.037862	0.038978	0.040121	0.041288	0.042481	0.043700	0.044945	0.046218
110	.047517	.048844	.050200	.051583	.052995	.054436	.055907	.057407	.058937	.060498
120	.062090	.063713	.065367	.067054	.068772	.070524	.072308	.074126	.075978	.077863
130	.079784	.081739	.083729	.085755	.087817	.089915	.092050	.094222	.096431	.098678
140	.10096	.10329	.10565	.10805	.11049	.11297	.11550	.11806	.12066	.12331
150	.12599	.12872	.13149	.13431	.13716	.14006	.14300	.14599	.14903	.15210
160	.15523	.15840	.16161	.16487	.16818	.17153	.17493	.17838	.18188	.18543
170	.18902	.19266	.19636	.20010	.20389	.20773	.21163	.21557	.21956	.22361
180	.22771	.23186	.23607	.24032	.24463	.24900	.25342	.25789	.26241	.26699
190	.27163	.27632	.28107	.28588	.29074	.29565	.30063	.30566	.31072	.31590
200	.32111	.32637	.33171	.33708	.34252	.34802	.35359	.35921	.36490	.37064
210	.37645	.38232	.38825	.39425	.40030	.40642	.41261	.41885	.42517	.43154
220	.43798	.44449	.45106	.45769	.46440	.47116	.47800	.48490	.49187	.49891
230	.50601	.51318	.52042	.52773	.53511	.54256	.55008	.55767	.56533	.57306
240	.58086	.58873	.59667	.60469	.61278	.62094	.62917	.63748	.64586	.65432
250	.66285	.67146	.68014	.68889	.69773	.70664	.71562	.72469	.73383	.74305
260	.75235	.76172	.77118	.78072	.79034	.80003	.80981	.81967	.82961	.83963
270	.84974	.85993	.87021	.88056	.89101	.90154	.91215	.92285	.93364	.94451
280	.95548	.96653	.97767	.98890	1.0002	1.0116	1.0231	1.0347	1.0464	1.0582
290	1.0701	1.0821	1.0941	1.1063	1.1186	1.1309	1.1434	1.1559	1.1686	1.1814
300	1.1942	1.2072	1.2203	1.2335	1.2467	1.2601	1.2736	1.2873	1.3010	1.3148
310	1.3288	1.3428	1.3570	1.3713	1.3857	1.4003	1.4149	1.4297	1.4446	1.4597
320	1.4749	1.4902	1.5056	1.5212	1.5369	1.5527	1.5687	1.5848	1.6011	1.6175
330	1.6341	1.6509	1.6678	1.6848	1.7020	1.7194	1.7370	1.7547	1.7726	1.7907
340	1.8090	1.8275	1.8461	1.8650	1.8841	1.9033	1.9228	1.9426	1.9625	1.9827
350	2.0031	2.0238	2.0448	2.0660	2.0874	2.1092	2.1313	2.1536	2.1763	2.1993
360	2.2226	2.2463	2.2704	2.2948	2.3196	2.3449	2.3705	2.3966	2.4232	2.4503
370	2.4779	2.5060	2.5346	2.5639	2.5938					

TABLE 7.
VAPOR PRESSURE IN INT. ATM. OF WATER BELOW 100°.

$t^{\circ}\text{C.}$	$p^{\text{mm.}}$	$p^{\text{I. A.}}$	$p^{\text{I. A.}}$	$\left(\frac{dp}{dt}\right)^{\text{mm.}}$	$\left(\frac{dp}{dt}\right)^{\text{I. A.}}$	$\left(\frac{dp}{dt}\right)^{\text{I. A.}}$
	Eq. 2	Eq. 2	Eq. 1	Eq. 2	Eq. 2	Eq. 1
-15	1.4400	0.001895				
-10	2.1541	0.002834				
-5	3.1690	0.004170				
0*	4.5893	0.006039		0.3329	0.0004381	
5	6.5479	0.008616		0.4561	0.0006001	
10	9.2121	0.012121		0.6165	0.0008112	
15	12.7893	0.016828		0.8228	0.0010827	
20	17.5336	0.023070		1.0851	0.0014278	
25	23.7530	0.031254		1.4149	0.0018618	
30	31.8172	0.041865		1.8253	0.0024017	
35	42.1647	0.055480		2.3308	0.0030669	
40	55.311	0.072778		2.9479	0.0038788	
45	71.860	0.09455		3.6944	0.0048610	
50	92.503	0.12172	0.12165	4.5898	0.0060392	
55	118.041	0.15532		5.6555	0.0074414	
60	149.380	0.19655	0.19652	6.9141	0.0090975	
65	187.544	0.24677		8.3902	0.0110397	
70	233.687	0.30748	0.30748	10.1094	0.013302	
75	289.094	0.38039		12.099	0.015920	
80	355.175	0.46734	0.46736	14.388	0.018931	
85	433.512	0.57041		17.004	0.022374	
90	525.818	0.6919	0.6919	19.980	0.026290	0.026281
95	633.968	0.8342	0.8342	23.347	0.030720	0.030718
100	760.000	1.0000	1.0000	27.137	0.035706	0.035703
105	906.095	1.1922	1.1922	31.382	0.041292	0.041288
110	1074.63	1.4140	1.4140	36.117	0.047522	0.047517
120	1489.31	1.9596	1.9595	47.191	0.062093	0.062090
130	2026.3	2.6662	2.6662	60.631	0.079777	0.079784
140	2710.7	3.5668	3.5668	76.712	0.10094	0.10096
150	3570.3	4.6977	4.6983	95.707	0.12593	0.12599

* Sub-cooled water, triple point 0.01° C.

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THE SYNTHESIS OF AMMONIA IN THE
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BY WALTER C. SCHUMB AND LOUIS GOLDMAN.

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THE SYNTHESIS OF AMMONIA IN THE ELECTRODELESS DISCHARGE.

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EQUILIBRIUM studies dealing with the system nitrogen-hydrogen-ammonia in electrical discharges are chiefly of early date and the recorded data are not in very good agreement. As distinct from the numerous qualitative observations of early investigators upon the union of nitrogen and hydrogen in electrical discharges, Thénard¹ first noted that when ammonia is formed in the ozonizer from a mixture of nitrogen and hydrogen at one atmosphere the reaction progresses until 3% of ammonia by volume has been formed. Berthelot² found that ammonia gas decomposes until the gas mixture contains 3% ammonia, concluding that the reaction is of the reversible type and that equilibrium is thus attained from either side. Le Blanc and Davies,³ using a stoichiometric mixture of nitrogen and hydrogen at one atmosphere in an ozonizer obtained an equilibrium mixture containing 2.8% ammonia. Günther-Schulze,⁴ working in the pressure range 6 to 30 mm., reported that a mixture of nitrogen and hydrogen is not affected by the glow discharge and that ammonia is completely decomposed. In a corona discharge at 20,000 volts and 60 cycles, Wendt and Snyder⁵ found 4.1% ammonia in the equilibrium mixture. Recently Westhaver⁶ obtained approximately 6% of synthesis in the equilibrium mixture resulting from the action of a glow discharge upon a stoichiometric mixture of nitrogen and hydrogen; and also reported the presence of hydrazine in the products formed from ammonia in the positive column of the discharge. The effect of fresh machining of the surface of the metal electrodes was noted and the temperature of the tube was varied up to 400°. It has been pointed out by de Hemp-

¹ Thénard: *Compt. rend.*, 76, 983 (1873); *Fortschr. d. Phys.*, 29, 754 (1873).

² Berthelot: *Compt. rend.*, 2, 1360 (1876); *Ann. Chim. Phys.*, 67, 218 (1908); *Fortschr. d. Phys.*, 32, 1020 (1876); *Bull. Soc. Chim.*, 2, 101 (1876).

³ Le Blanc and Davies: *Z. Elektrochem.* 14, 361 (1908).

⁴ Günther-Schulze: *Z. Elektrochem.*, 30, 386 (1924).

⁵ Wendt and Snyder: *J. Am. Chem. Soc.*, 50, 1288 (1928).

⁶ Westhaver: *J. Phys. Chem.*, 37, 897 (1933).

tinne⁷ as well as by others, that the effect of excess nitrogen and of hydrogen on the equilibrium in an electric discharge is not in accord with the requirements of the law of mass action.

The present investigation was undertaken with the purpose of studying the equilibrium in the system nitrogen-hydrogen-ammonia in an electrodeless discharge under known conditions of current strength, frequency, and pressure, over as wide a range as possible. It was proposed, furthermore, to determine the amount of ammonia synthesized—or left undecomposed, as the case may be—not only by observations of the pressure changes resulting from the action of the discharge, but also by direct colorimetric determinations carried out upon the gas mixture when equilibrium had been attained. It was also hoped that new light might be brought to bear upon the known lack of applicability of the law of mass action on the ammonia equilibrium in electrical discharges.

EXPERIMENTAL

Preparation of Ammonia.—Commercial anhydrous ammonia was condensed upon sodium and twice fractionally distilled, the middle portion alone being collected each time. After chilling with liquid air, the bulb containing the solid ammonia was evacuated to .0001 mm. and the ammonia finally collected in the gaseous form in a thoroughly evacuated 3-liter bulb, provided with a mercury seal in place of a stopcock (A in Fig. 1).

Preparation of Nitrogen-Hydrogen Mixture.—A mixture of nitrogen and hydrogen, 1 : 3 by volume, was used in all the experiments upon the synthesis of ammonia. This mixture was obtained by decomposing purified gaseous ammonia at 1.5 mm. in an electrodeless discharge. The oscillator used for this purpose was a single tube set employing a 50 watt UV-203A tube. The operating wave length was 34 m., corresponding to a frequency of 8820 k.c. This set was described in an earlier paper.⁸ Experiments had shown that at about 30 m. complete decomposition of the ammonia was effected, as indicated both by the pressure change and by the negative results given by Nessler's reagent with the resulting gaseous mixture. In order to obviate the danger of contamination of the gas mixture by gases driven from the walls by the discharge, the bulb was subjected during evacuation to a discharge operating at a higher current strength than that used subsequently

⁷ de Hemptinne: Z. Physik. Chem., 22, 358 (1897).

⁸ Hunt with Schumb: J. Amer. Chem. Soc., 52, 3152 (1930).

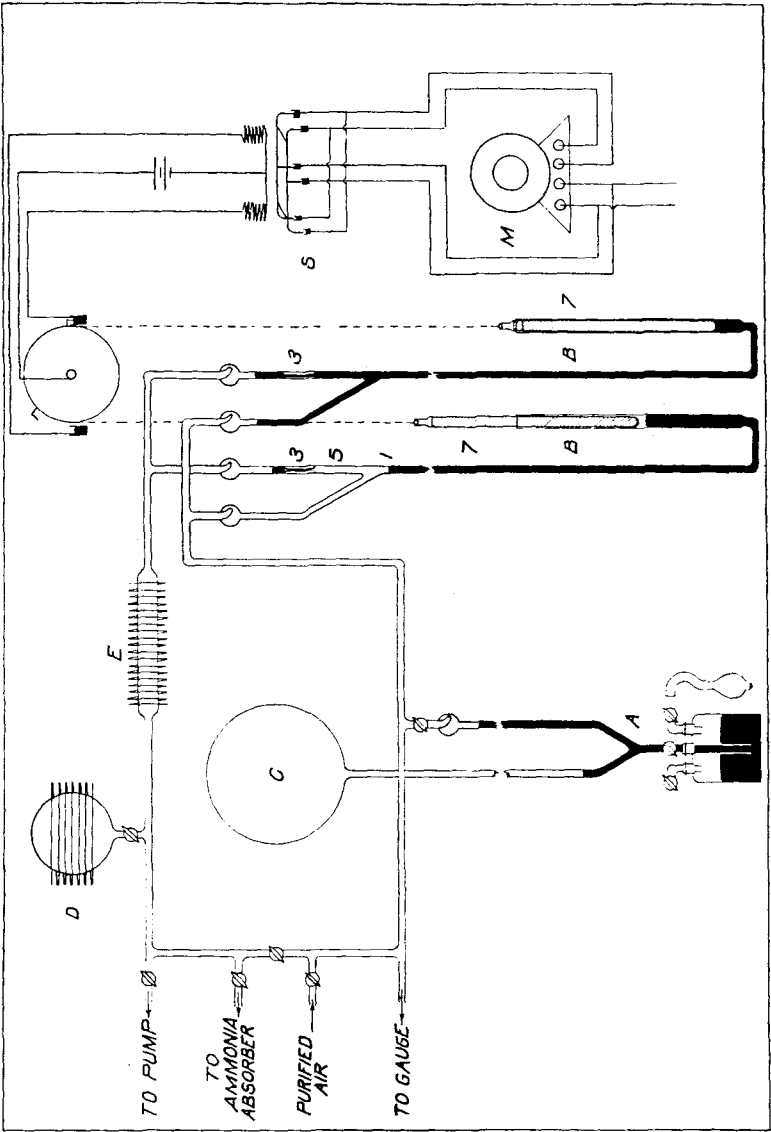


FIGURE 1.

in the decomposition of the ammonia. This process will be referred to below as "preglowing."

Oscillators.—With the spark gap assembly employed in earlier work⁹ in which high yields of ammonia had been reported, the wave length obtained was about 260 m. Because of the variability of the characteristics of this assembly, a tube set was designed which could be operated over the range 200–500 m. A standard Hartley circuit was used, with a 250-watt General Electric Company radiotron, type UV-204A (see Fig. 2). With this set a current of 5 to 10 amperes could be obtained in the solenoid between 200 and 300 m. by varying the plate voltage. The solenoid consisted of a nickel-plated copper strip, 9 mm. wide and 1.2 mm. thick, wound as a flat spiral of 24 turns with about 8 mm. spacing between turns, and an inside diameter of 15.5 cm. 14 turns of the spiral were in the oscillating circuit and 24 turns in the grid-to-plate circuit. For operations at lower wave lengths (10–40 mm.) a four tube oscillator operating from the same power pack was available, the detailed wiring of which is also shown in Fig. 2. When the high frequency oscillator was in operation the leads at A, B, C, and D were disconnected from the low frequency oscillator. When the low frequency oscillator was in operation the leads at A, C, and D were disconnected from the high frequency oscillator.

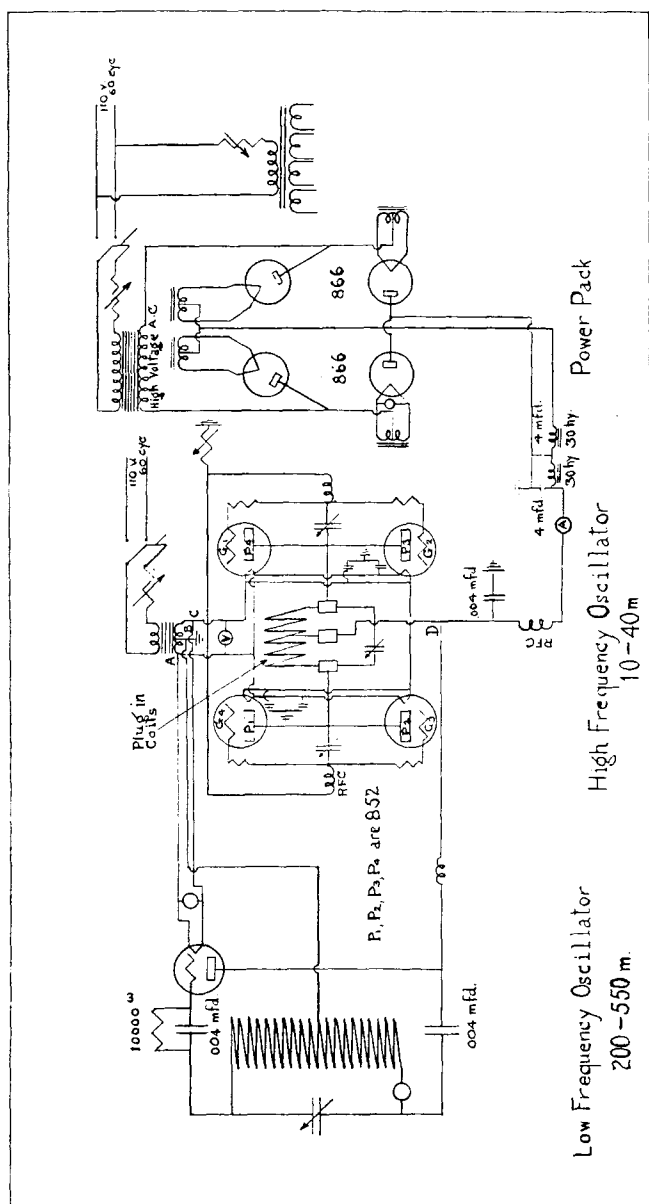
In the construction of this apparatus a grant from the American Academy of Arts and Sciences was of material assistance, which is hereby gratefully acknowledged. The design and the construction of the oscillators are due to Mr. F. M. Gager, formerly a member of the staff of the Department of Electrical Engineering of this Institute.

Circulation of Gas Mixture.—The mixture of nitrogen and hydrogen was circulated through the discharge tube, because it was believed that the yield of ammonia so obtained would be greater than that resulting from the discharge in a static system. It has been demonstrated by van der Wyk¹⁰ and by Briner and Baerfuss¹¹ that when a stream of nitrogen and hydrogen passes through an electric discharge, the yield of ammonia rises with the rate of flow. These investigators, however, were not studying equilibrium conditions as is the case in the present work. A second advantage of the circulation method in the synthesis of ammonia lies in the fact that the volume of the "dead

⁹ Schumb and Hunt: J. Phys. Chem., **34**, 1919 (1930).

¹⁰ van der Wyk: J. Chim. Phys., **25**, 251 (1928).

¹¹ Briner and Baerfuss: J. Chim. Phys., **17**, 71 (1919).



space," containing gas that is not subjected to the influence of the discharge, in this method is reduced practically to the volume of the bulb of the McLeod gauge alone, because of which fact the correction which must be applied to the observed change in pressure of the system, in order to be able to calculate percentage of synthesis attained, is reduced to about the magnitude of the experimental error.

The circulation pump is shown in Fig. 1. The two plungers (7) were glass tubes partially filled with mercury which sank by the action of gravity in the two wells, also containing mercury, and were attached by a chain to a sprocket above, which turned upon a shaft geared to a small speed reducer (not shown in the figure) which in turn was operated by a D.C. motor (M). The direction of rotation of the motor was reversed after the proper intervals of time by the rocking switch, or relay (S), which was wired to two contacts on the sprocket. When a plunger sank, the mercury rose in the narrow tube to a point above the capillary (3); when the plunger rose, the mercury fell in the narrow tube to a point below the T, through which gas entered the vacuum left in the upright tube (5). Due to the capillary portion (3), a quantity of mercury remained above (3), sealing the capillary and thus acting as a valve; the time required for the plug of mercury to empty through the capillary was greater than that required for the column of mercury below the capillary to fall to (1) and to rise again to (3). With the rising stroke gas was forced through the mercury valve and so into the rest of the apparatus. The two pistons, operating alternately and in parallel, made about 25 strokes each per minute and brought about a circulation of about 250 cc. of gas mixture per minute at 1 to 2 mm. pressure.

(C) was a 3-liter reservoir in which purified ammonia was stored, confined by a mercury seal. (D) was a liter bulb in which ammonia at 1.5 mm. was completely decomposed by the action of an electrodeless discharge as above described. When the nitrogen-hydrogen mixture had been admitted from (D) into the circulating system at a known pressure, the pumps (B) circulated the gas through the discharge tube (E). This reaction chamber was evacuated and baked at 350° C. for one hour before each run. The pressure in the system before and after the discharge—time being allowed for cooling to the original temperature—was read upon a McLeod gauge.

STUDY OF THE WALL EFFECT.

That the synthesis of ammonia is a wall reaction has been clearly indicated by the work of Pohl,¹² Warburg and Rump,¹³ Alsfeld and Wilhelmy,¹⁴ and others. Consequently, to hope for any satisfactory degree of reproducibility in results, the proper conditioning of the walls of the reaction vessel is essential. Preglowing of the reaction tube proved inadequate for this purpose, as erratic values with a general downward trend for the percentage of ammonia synthesized in a series of runs were obtained. It was observed that if the reaction tube was baked while being highly evacuated for one hour at a temperature of 350° C., a reproducible pressure drop could be obtained in a subsequent run. These conditions of temperature and time of baking were adopted as standard procedure in the pre-treatment of the reaction vessel, because it was found that if the tube was baked at 450° C. instead of 350° C., or for two hours instead of one hour, no difference in the pressure drop resulted.

Effect of Increased Surface.—To magnify the effect of the surface exposed in the reaction vessel, a tube was filled with glass wool and thoroughly evacuated. Without further pretreatment a pressure drop was obtained upon a stoichiometric mixture of nitrogen and hydrogen corresponding to a large percentage of synthesis (as high as 36%); successive experiments with fresh gas mixtures and with evacuation between runs, however, showed rapidly diminishing pressure drops, approaching a small value (about 10%). If the tube was now allowed to stand for a number of hours a larger percentage of synthesis was again obtained, but succeeding runs again showed rapidly decreasing values approaching approximately the same final value previously obtained.

The effect of variation in surface is further seen in the results obtained with two tubes of dimensions as nearly alike as possible, in which the nitrogen-hydrogen mixture was subjected to the discharge under the same conditions. Thus a Pyrex tube of 18 mm. inside diameter, 37 cm. long (referred to below as No. 1) containing no glass wool, pre-treated by the standard procedure, at 277 m. and 7 amp. gave a reproducible pressure drop of $.062 \pm .002$ mm.; while a similar but different tube (No. 2) under the same conditions gave a pressure drop

¹² Pohl: Ann. d. Phys., 21, 879 (1906).

¹³ Warburg and Rump: Zeit. f. Phys., 40, 557 (1927).

¹⁴ Alsfeld and Wilhelmy: Ann. d. Phys., 8, 89 (1931).

of $.045 \pm .002$ mm. This difference in results shown by the two tubes is discussed below.

In a separate series of experiments, instead of the use of glass wool to afford increased surface, a larger reaction tube, 30 cm. long and 53 mm. inside diameter, was employed. Using this larger reaction tube, the total volume of the *system* was approximately doubled (from about 600 to 1200 cc.), and the surface area of the *reaction tube* alone likewise was about doubled; the pressure drop obtained, however, was nearly the same as that given by tube 2 (.047 mm., at 265 m., 7 amp.). These data indicate that the amount of ammonia formed in the large tube is twice that produced in the small tube. Ammonia formation is, therefore, proportional to the surface area exposed in the reaction tube.

If the reaction tube was baked *after* a run a rise of pressure was noted (the measurement being made as usual after cooling to room temperature). Thus, in a particular experiment, the following data were obtained:

Wave length = 277 m. Current = 7 amp. Reaction tube No. 1

Initial Pressure (mm.)	Final Pressure (mm.)	Pressure after Baking (mm.)	Pressure after a Second Baking (mm.)
1.057	1.000	1.024	1.024

Thus, the ammonia formed by the action of the discharge is in part retained on the walls of the vessel and is later driven out by the baking.

A somewhat perplexing situation was encountered when it was observed that, while subjecting the nitrogen-hydrogen mixture to the electrodeless discharge for 15 minutes gave the same net pressure drop as a 30-minute run, nevertheless a series of 15-minute runs on the same gas mixture (with intervals for cooling and measuring pressure) gave further pressure drops after each run as shown in the following table, which records the pressure drops obtained in successive 15-minute runs on the same gas mixture:

Wave length = 277 m. Current = 7 amp. Reaction Tube No. 1

Initial Pressure (mm.)	Pressure Drops (mm.)					
	1	2	3	4	5	6
1.020	.060	.014	.012	.003	.011	.010
1.026	.063	.010	.010	.008		

Furthermore, if the reaction tube was baked between the successive 15-minute runs, larger pressure drops than those recorded in the preceding table were obtained, as shown in the following table:

Wave length = 260 m. Current = 7 amp. Reaction Tube No. 2
Initial Pressure = 1.012 mm.

Run	Pressure Drop (mm.)	Pressure Rise after Baking (mm.)	Net Pressure Drop (mm.)
1	0.047	0.016	
2	.025	.011	
3	.022	.013	
4	.018	.012	0.060

Discussion.—Consideration of the results of the experiments above described leads us to the following interpretation of the part played by the walls of the reaction vessel in the formation of ammonia. Active particles of nitrogen and of hydrogen, formed in the gas phase, collide upon the wall and form ammonia. The reaction continues until the surface is covered with a layer of adsorbed ammonia, whereupon further synthesis ceases to occur, no matter how long the discharge be continuously operated. At the steady state thus established ammonia evaporates from the wall at the same rate at which it is being formed on the wall. In accordance with the views of J. and W. Taylor¹⁵ on the nature of the dark annular space adjacent to the walls of the discharge vessel, the ammonia adsorbed on the wall would be expected to escape decomposition. These authors point out that the dark space is due to the fact that the negatively charged wall prevents almost completely the entrance of electrons into the gas layer contiguous to

¹⁵ J. and W. Taylor: Proc. Cambridge Phil. Soc., 24, 263 (1928).

the wall. The adsorbed ammonia therefore, is not subjected to electron bombardment and remains undecomposed.

The observations recorded above, together with other considerations discussed below, may be interpreted in the light of this hypothesis, as follows:

(1) A given tube, used repeatedly with successive portions of a given gas mixture, exhibited a definite fatigue effect—due to the accumulation of adsorbed ammonia on the walls—finally ceasing altogether to bring about synthesis; but by baking the reaction vessel before each run in the manner described, reproducible pressure drops were obtained. The effect of the baking and evacuating is obviously to bring the walls into the same condition before each run by clearing them of adsorbed gas.

(2) A tube filled with glass wool and evacuated gave a much higher yield of ammonia than the same tube without glass wool. Repeated runs with the glass wool, with no pre-baking, gave rapidly diminishing pressure drops approaching a small value, the magnitude of which did not appreciably alter in subsequent runs. The initial high value was caused by the great surface exposed by the glass wool; the rapid decrease in the pressure drops was due to the accumulation of adsorbed ammonia; the constant magnitude of pressure drop obtained after a number of runs was brought about when the surface of the glass wool was covered with adsorbed gas, the evaporation of which during evacuation between runs exposed roughly equal areas.

(3) The difference in the results obtained with two similar tubes under the same conditions, as described above, is not surprising when it is remembered that, although the macrostructure of the two tubes might appear to be very similar, the microstructure of the walls of the tubes may be sufficiently different to account for considerable difference in surface area; and ammonia formation, as previously stated, is proportional to the surface area exposed in the reaction tube.

(4) The pressure rise resulting from baking of the reaction tube after a run is due to the driving out of adsorbed ammonia from the walls.

(5) A series of four 15-minute runs had a much greater effect than a single run of an hour's duration, due to the fact that when the tube is allowed to stand for a short time, opportunity is given for some of the ammonia to evaporate into the gas-filled space, exposing fresh wall surface and hence permitting further synthesis to occur when the discharge is again operated. If the reaction tube is baked in the

interval between runs, the larger pressure drops obtained are due to the fact that baking exposes a greater surface than that resulting from evaporation at room temperature.

(6) *Colorimetric confirmation.*—Furthermore, if the ammonia remaining in the gaseous condition in the tube after a run was thoroughly swept out with well-dried nitrogen, absorbed in very dilute sulphuric acid, and determined colorimetrically (Nesslerization), an additional quantity of ammonia subsequently could be obtained by baking the reaction vessel and again sweeping out the ammonia thus released from the walls of the vessel with dry nitrogen.

The absorption of ammonia was carried out in a glass tube 20 mm. wide and about 70 cm. long, supplied with a series of ten constrictions, the whole tube being held in a position slightly inclined from horizontal. The gas passed slowly over the surface of the absorbing liquid and bubbled through the liquid at the constrictions.

By means of this process a reasonably good check between the amount of synthesis calculated independently from the pressure drops and from the colorimetric determinations was afforded. Unless the reaction tube was baked after operating the discharge, only a fraction of the ammonia formed by the discharge could be swept out by the nitrogen. A typical run which illustrates these facts, furnished the following data:

I = 7 amp. λ = 280 m. Reaction tube No. 2

Initial press. of mixture (mm.)	Pressure drop (mm.)	Press. rise after bak- ing (mm.)	Net press. drop (NH ₃ formed) (mm.)	NH ₃ in gas phase (before baking) (mm.)	%NH ₃ in gas (be- fore baking) (mm.)	NH ₃ found colorim. (after baking) (mm.)
1.040	0.042	0.017	0.025	0.008	32	0.023

Similarly, the net pressure drop, 0.060 mm., recorded in the table on page 177 was confirmed colorimetrically, the quantity of ammonia found by Nesslerization corresponding to a pressure drop of .051 mm.

EFFECT OF VARIATION IN FREQUENCY, CURRENT, AND INITIAL PRESSURE.

In the accompanying graphs, Figs. 3 to 8, the effects of alteration of frequency, current, and initial pressure on pressure drop, over the

range permitted by the apparatus, are shown. In Fig. 3 drop in pressure is plotted against wave length for an initial pressure of 0.55 mm. Fig. 4 shows similarly the results for an initial pressure of 1.05 mm., with currents of 5, 6, 7, and 8 amps. flowing through the solenoid. It will be seen that the pressure drop rises with the frequency at a rate faster than linear. The intensity of the glow was observed to increase with frequency. Figs. 5 and 6 indicate the increase in pressure drop with increasing current, at constant frequency; and fig. 7 shows the

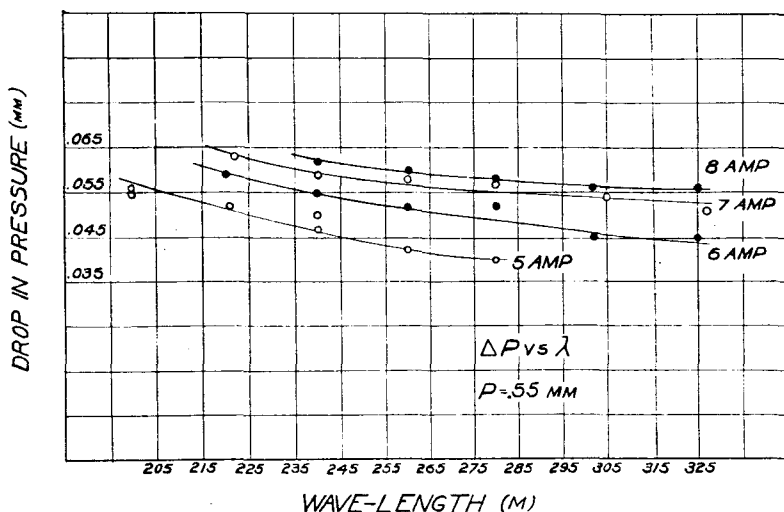


FIGURE 3.

effect of change in the initial pressure upon the drop in pressure obtained. With increasing initial pressures the pressure drop is seen to decrease. In the hypothesis above advanced of the mechanism of the reaction, no indication is given of such an effect of variation in initial pressure; for it would seem that if the reaction proceeded until the walls of the vessel had become inactive due to a film of adhering ammonia molecules, then the drop in pressure should be independent of the initial pressure. Other effects evidently are responsible for the observed results, such as the change in conductivity with changing pressure, and the rise in the mean free path as pressure decreases, which facilitates access of active particles to the walls of the reaction vessel.

It was thought desirable also to observe the effect upon the pressure drop of variation in frequency at *constant energy output* of the solenoid, which, in general, was an unknown quantity. In order to obtain a satisfactory measure of the energy output of the solenoid, the expedient was adopted of observing the rise in temperature brought about when the bulb of a mercurial thermometer was placed approximately at the center of the solenoid (the glass reaction vessel being absent), and the discharge operated at known frequencies and current

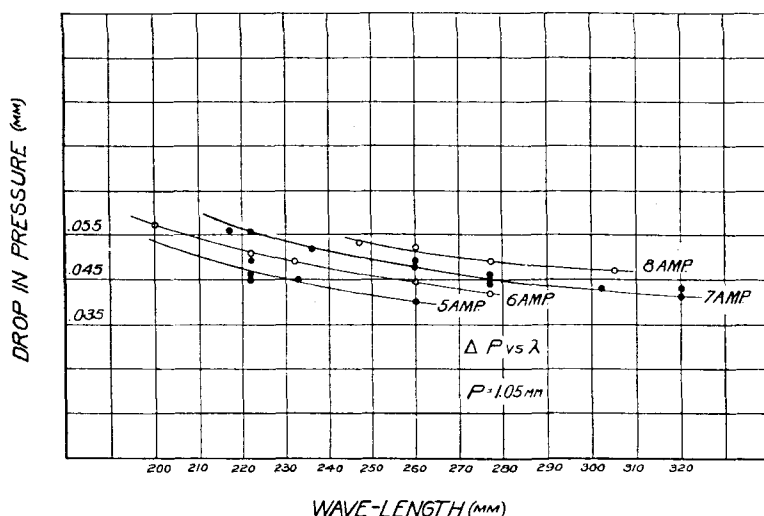


FIGURE 4.

strengths until a constant temperature was reached. When the rise of temperature was plotted against wave length at 5, 6, 7, and 8 amp., a series of parallel lines was obtained. The energy output of the solenoid was then taken as constant for such combinations of wave length and current as gave the same temperature rise. From Fig. 8, wherein pressure drop is plotted against wave-length at constant energy output of the solenoid, it is seen that the pressure drop rises at an *accelerated* rate with increasing frequency; this indicates that frequency has a specific effect upon the pressure drop produced, and that the rise of the latter with frequency is not simply the effect of changing energy output accompanying the change in frequency.

Because of the fact that the pressure drop rises with frequency at

a rate faster than linear, and because the pressure drop obtained at 265 m. and 7 amps. was .047 mm., while at 18 m. a pressure drop of .028 mm. was obtained with the same prebaking procedure, the conclusion may be drawn that at some intermediate frequency the extent of synthesis passes through a maximum. This evidence is not complete, however, as the ampere-turns for the 18 m. measurements were not the same as in the 265 m. measurements, there being no way to determine accurately the current in the solenoid at 18 m. Experi-

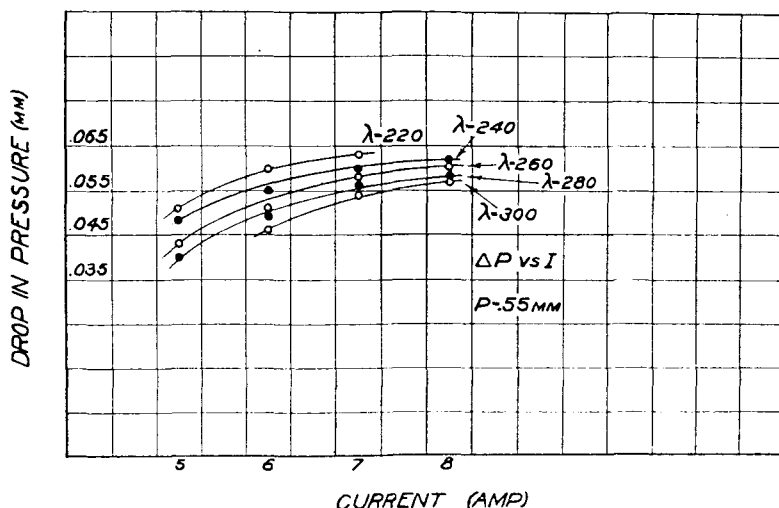


FIGURE 5.

tation is at the present time under way with the object of studying this matter further, by extending the wave length range below 200 m. as far as possible with the Hartley oscillator.

APPROACH TO THE STEADY STATE FROM THE AMMONIA SIDE.

Consideration of the phenomena occurring in the nitrogen-hydrogen mixture in the electrodeless discharge naturally suggests a comparison of the steady state conditions attained in this case with those resulting from the operation of the discharge in ammonia gas. Starting, for example, with ammonia at 0.5 mm., or with the stoichiometric nitrogen-hydrogen mixture at 1.0 mm., it might be expected that under the same conditions and in the same tube the pressure drop obtained with

the second mixture should equal $2P_i - P_f$, where P_i is initial pressure of ammonia and P_f the final pressure of the mixture.

A satisfactory confirmation of this premise was obtained, as will be shown in the following table; but only after due allowance was made for the adsorption of ammonia by the walls of the tube when the gas was admitted after the customary baking and evacuation of the vessel.

The first two columns of the table give the observed initial pressure of ammonia and the values of $(2P_i - P_f)$ after the discharge. The

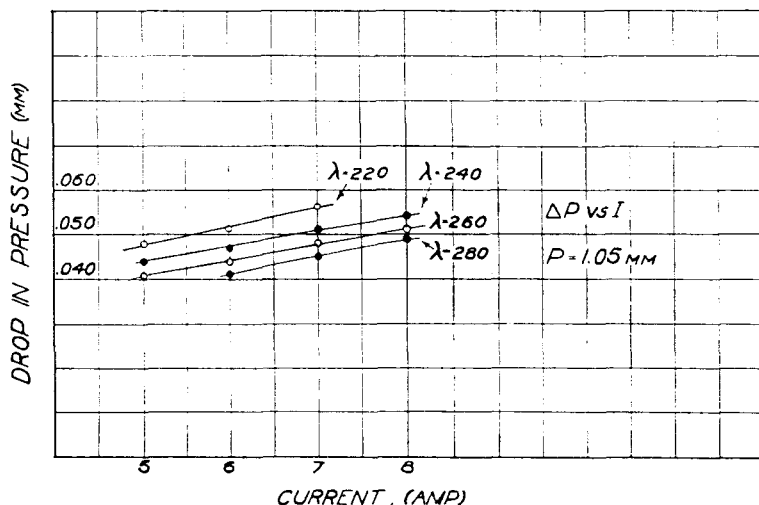


FIGURE 6.

third and fourth columns show the initial pressure and the drop in pressure obtained when the $N_2 : 3H_2$ mixture at about 1 mm. was subjected to the discharge under the same conditions, the tube having been baked and evacuated as usual. It will be noted that ΔP in column 4 is about twice as large as $2P_i - P_f$ in column 2. This lack of agreement, at first sight somewhat puzzling, appears quite reasonable when examined more closely in the light of the hypothesis advanced above. When ammonia is introduced into the freshly baked and evacuated reaction bulb some gas is adsorbed by the walls before the initial pressure is read, and the active area exposed is reduced in extent. When the ammonia gas is decomposed in the discharge only a relatively small surface is left free upon which ammonia may be

formed by recombination of the nitrogen and hydrogen particles so produced.

In order to test this explanation of the lower values of $2P_i - P_f$ (column 2) as compared to ΔP (column 4), a third series of runs was made, as shown in columns 5 and 6, in which the walls of the reaction vessel were "rinsed" with ammonia before admitting the $N_2:3H_2$ mixture to be subjected to the discharge. The tube was first well baked and evacuated; ammonia was then introduced at .5 mm. and

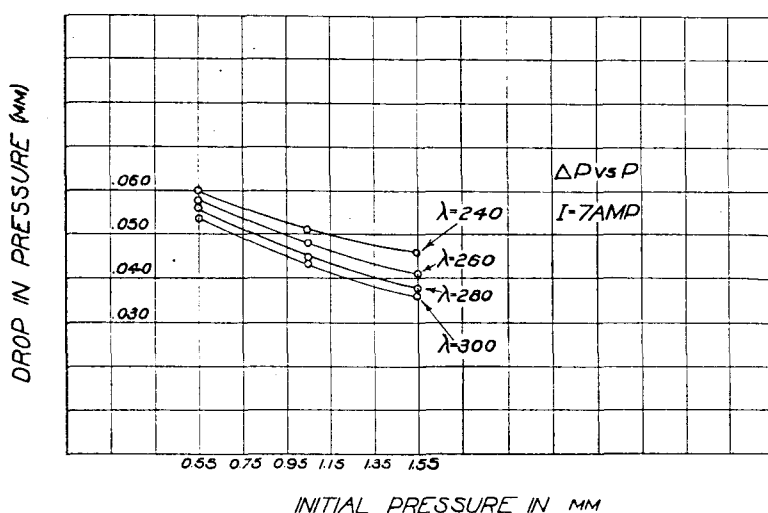


FIGURE 7.

$\lambda = 265 \text{ mm.}$ $I = 7 \text{ amp.}$ Reaction tube, $380 \times 18 \text{ mm., I.D.}$

P_{iNH_3} (mm.)	$2P_i - P_f$ (mm.)	$P_{i(N_2+3H_2)}$ (mm.)	ΔP (mm.)	$P_{i(N_2+3H_2)}$ (mm.)	ΔP (mm.)
0.502	0.024	1.056	0.044	1.100	0.022
.480	.020	1.002	.048	1.045	.019
.510	.020	1.016	.045	1.027	.025
.541	.022	—	—	—	—

the tube again evacuated; finally the $N_2:3H_2$ mixture was admitted and the run conducted as usual. The agreement observed in a comparison of columns 6 and 2 indicates that the same steady state is

reached whether starting with ammonia at 0.5 mm. or with the nitrogen-hydrogen mixture at 1.0 mm.

Ammonia Synthesis in a Static System.—In conclusion, it is of interest to note, and to interpret in the light of the hypothesis presented above, the effect produced by substitution of a static system for the circulatory arrangement employed in all the preceding work. If, as we have postulated, in the case of the discharge in the nitrogen-hydrogen mixture, synthesis proceeds until the wall becomes covered

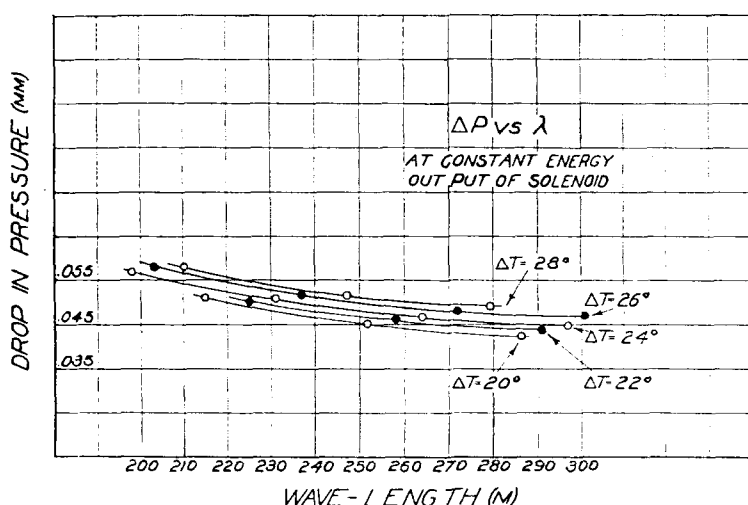


FIGURE 8.

with a layer of adsorbed ammonia, then, given two reaction tubes of equal volumes, one of them a part of a circulatory system such as has been described, the other forming a part of a static system of distinctly less total volume, we should expect to obtain much larger pressure drops with the static system, since the same number of molecules are being removed (as ammonia is formed) from a much smaller volume.

Large pressure drops were in fact observed in a series of experiments with a static system wherein the reaction tube, sealed at one end, was connected directly to the McLeod gauge. At 267 m. and 7 amp., the following data were obtained with the $N_2 : 3H_2$ mixture at about 1 mm.:

Initial Pressure Drop (mm.)	Rise on Baking (mm.)	Net Pressure Drop (mm.)
0.362	0.138	0.244
.364	.141	.223
.382	.152	.230

Although the agreement in the three runs is poorer than that obtained in the runs with the circulatory system, it is, nevertheless, certain that the initial pressure drops are much larger than those noted in the previous work—0.37 mm. in the static method, as compared with 0.046 mm. under the same conditions in the circulatory system. The total volume of the static system was approximately 50 cc. as compared with approximately 550 cc. in the circulatory system.

The distribution of ammonia between the walls and the gas space is about the same in the two cases, but in the circulatory method more ammonia is formed both on the walls and in the gas space, as will be made evident by the consideration of the following data:

	Vol. of System (cc.)	Net press. drop = NH_3 formed (mm.)	Press. rise on baking = NH_3 released from walls. (mm.)	Total millimols NH_3 formed $\times 10^3$	Millimols NH_3 on walls $\times 10^3$
Circulatory Method	550.	0.028	0.018	0.83	0.53
Static Method	50.	0.23	0.14	0.62	0.38

SUMMARY.

1. A study has been made of the synthesis of ammonia from a stoichiometric mixture of nitrogen and hydrogen, at pressures of from 0.5 to 1.5 mm., when submitted to the influence of an electrodeless discharge operated over the wave-length range 200–330 mm., with current strengths of from 5 to 8 amps. in the solenoid. The calculations of the amount of ammonia synthesized from the observed pressure change, when due provision was made for driving out the gases adsorbed by the walls, were shown to correspond with the quantity of

ammonia contained in the system by colorimetric determinations carried out upon the resulting gas mixture.

2. Since the synthesis of ammonia in this manner is known to be a wall reaction, various expedients were tried to observe the effect of the extent and condition of the wall surface exposed to the reacting mixture, and from the data obtained an hypothesis has been advanced for the mechanism of formation of ammonia in the discharge vessel.

3. The hypothesis proposed accounts for the data obtained in a study of the following aspects of the wall effect:

a. The necessity of adequate pretreatment of the reaction vessel, consisting of evacuation and baking, in order to obtain reproducibility of results.

b. The effect of increased surface by the use of glass wool.

c. The comparison of results obtained under as nearly as possible identical conditions with two different reaction tubes of closely similar dimensions.

d. The comparison of results obtained with a small and with a large tube under like conditions, leading to the conclusion that the formation of ammonia is proportional to the surface exposed.

e. The rise in pressure brought about by baking of the reaction tube after a synthesis run.

f. The continued pressure drops obtained when the same gas mixture was subjected repeatedly to the discharge, with short intervals of time for cooling and measurement of pressure.

g. The approach to the same final state, whether starting with the nitrogen-hydrogen mixture or with ammonia. In the former case "rinsing" of the walls of the tube with ammonia gas, prior to admitting the nitrogen-hydrogen mixture, was found necessary in order that the same final state be realized.

h. The agreement obtained in the estimation of the quantity of ammonia synthesized by pressure measurements and by colorimetric analysis.

4. It has been shown that much larger pressure drops are obtained in a static than in a circulatory system, a fact which is likewise in accordance with the hypothesis referred to above. More ammonia is formed in the circulatory system although the percentage distribution between wall and gas space is the same in both cases.

5. Evidence has been obtained indicating that the percentage of synthesis of ammonia, when plotted as a function of frequency, passes through a maximum.

6. The hypothesis advanced for the mechanism of the synthesis in the discharge leads to the conclusion, which has been repeatedly demonstrated experimentally, that the law of mass action should not be expected to apply to this case, as it is not a homogeneous gas phase reaction.

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STUDIES ON HISTOMONIASIS, OR "BLACKHEAD"
INFECTION, IN THE CHICKEN AND THE TURKEY.

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I. INTRODUCTION.

UNTIL the sources of blackhead infections were demonstrated and the manner of its transmission became known, this disease doubtless constituted the chief obstacle to turkey rearing in many regions of this country. Fifteen years ago there were relatively few turkeys to be found in New England and one who reared a flock of fifty or one hundred birds was looked upon as unusually successful. At the present time, flocks of several thousand are relatively common and in a recent season one turkey raiser succeeded in rearing nearly twelve thousand turkeys. Mass production has been made possible, first through the recognition and avoidance of the chief sources of infection, demonstrated by laboratory experiment to be mature poultry and contaminated soil, and second by the adoption of the incubator and the brooder house, which not only has made feasible the management of great numbers of poults but has at the same time avoided the more important sources of infection.

Aside from its economic aspect, blackhead infection presents features of unusual scientific interest. Blackhead is a disease brought about by the invasion of the tissues by the protozoön, *Histomonas meleagridis*, first recognized in 1895 by Theobald Smith. Subsequent investigations carried on over a period of many years in the Department of Comparative Pathology at Harvard have served to show that this organism is a flagellate which may be transmitted readily from bird to bird in various ways. In young turkeys, blackhead is progressive in character and therefore almost uniformly fatal. While

serious outbreaks occasionally occur in young chickens, the disease in this species is commonly mild and of brief duration. On recovery from the disease, the protozoön is eliminated from the tissues but may establish itself in the caecal contents in which it continues to multiply for an indefinitely long period. Hence the recovered bird commonly becomes a carrier and its discharges, often containing great numbers of the protozoön, are infective for normal birds. We have demonstrated direct transmission of infection not only by the feeding of caecal discharges containing *Histomonas*, but also by exposing normal birds both to carriers and to active cases of blackhead, such exposure being comparable to that occurring under natural conditions.

Since *Histomonas* survives for only a brief period in the material discharged from the caeca, cases of blackhead appearing in young birds that have never been associated with older stock can not be accounted for on the basis of direct transmission. Indeed the origin of many spontaneous cases of blackhead might be even now quite inexplicable were it not for the discovery of Graybill and Smith (1920) that blackhead may be produced by feeding large numbers of the embryonated eggs of *Heterakis gallinae*, the common caecal worm of poultry. While these authors offered the tentative hypothesis that the caecal worms lowered the resistance of the host to the protozoön supposed to be already present, the experimental data which I have collected show quite conclusively that the protozoön is carried by the worm egg. Its microscopic demonstration in the latter constitutes a more difficult problem than might be anticipated and all attempts to this end have been thus far unsuccessful, although *Histomonas* has been found developing in the intestinal epithelium of a certain proportion of immature caecal worms.

Histomoniasis appears to be unique in respect to its transmission through the agency of the caecal worm. While instances of the parasitization of intestinal worms by protozoa are recorded, no other example is known of an intestinal worm serving as the vector of an infectious disease. The study of *Histomonas* reveals many features of interest, as for example the phases of its protoplasmic activity, the variation in the appearance of the cytoplasm, the food materials utilized, the wide range in size of individual organisms, as well as inconstancy in respect to the number of flagella present.

From the ease with which experimental infection may be accomplished in incubator-hatched birds which are readily obtained free from all intestinal protozoa, certain problems, as, for example, varia-

tions in virulence and other modifications in biological character, may be undertaken with promise of success. Unlike those protozoan diseases of the human being, which either are not transmissible to lower animals or are not faithfully reproduced in the latter, blackhead lends itself to the study of immunological reactions. Finally, it is possible to make experimental studies of the epidemiology of this infection, in which all essential conditions are adequately controlled.

II. EXPERIMENTAL HISTOMONIASIS IN YOUNG TURKEYS AND CHICKENS, WITH OBSERVATIONS ON VARIOUS FORMS OF TYPHLITIS.

While certain methods of producing blackhead have long been employed by the author as a matter of laboratory routine, much of the resulting experimental data have not been reported. In order to work to advantage in the experimental investigation of this infection, it is essential for most purposes to employ incubator-hatched birds reared under laboratory conditions that will ensure freedom from intestinal protozoa as well as from infectious diseases. By placing birds, on removal from the incubator, in sterilized cages and providing them thereafter with sterilized dishes and sterile food, a stock may be readily kept free of any complicating infection for a period of several months. The success of the regime should be checked from time to time by microscopic examination of the caecal discharges for protozoa and by post mortem examination of any stock birds that may die. Attention also should be given to preventing access of flies or other insects and mice to the cages in which the birds are confined. "Day-old" chickens from certified flocks or "day-old" turkey poults have always been found quite satisfactory. Coccidium infection has appeared on occasion in the latter very early in life, but this is usually transient and need not seriously interfere with experimental work on blackhead.

Infection may be obtained by the introduction of materials containing numbers of living *Histomonas* into either the tissues or the alimentary tract of young chickens or turkeys. Success will depend in part on the mode of introduction and in part on the infectivity of the material utilized. *Histomonas* may be found in the following materials which may then be employed as inocula,—liver or caecal lesions in the acute stage from either spontaneous or experimental cases of blackhead, the caecal discharges of laboratory-reared carriers, cultures of *Histomonas*, and embryonated *Heterakis* eggs. The

caecal discharges when obtainable in cases of acute blackhead do not always contain *Histomonas*, but may be employed when this protozoön is microscopically demonstrable. *Histomonas* is seldom found in caecal cores and the use of the latter for inoculation usually yields only negative results. While the suitability of any diseased tissues for inoculation purposes is ordinarily judged by the number of *Histomonas* found on examination, this organism has never been observed in the *Heterakis* egg, and its presence in this case is demonstrated only by trial. Blackhead may be produced also by feeding henyard soil containing numbers of *Heterakis* eggs to young chickens or turkeys. Certain of the infective materials listed are only suitable for certain methods of inoculation. Thus, aseptically obtained liver lesions serve for any method of inoculation, including parenteral injection. *Heterakis* ova should be introduced into the alimentary tract, preferably by mouth, in order to hatch, and those materials containing *Histomonas* in association with bacteria are best introduced into the alimentary tract.

In experimental investigations on blackhead infection, the fact that *Histomonas* is much more pathogenic for young turkeys than for young chickens must be taken into account. Wide variation in the pathogenicity of this protozoön occurs, a subject which will be discussed in a subsequent section, but even with the more virulent strains the high mortality commonly observed in young turkeys is seldom encountered in young chickens. Thus while recovery from clinical blackhead is extremely rare in turkeys under two months of age, fatal cases in chickens are quite uncommon.

The influence of age on the course of the infection should also be taken into account especially when mature or nearly mature turkeys are utilized. There is a widespread belief that turkeys more than four or five months old never suffer from blackhead, but this is erroneous, since the disease often appears in older birds, which, however, more frequently recover and it is probable that there are also sub-clinical cases of infection. It is a common experience for turkey raisers to lose considerable numbers of year-old turkey hens from blackhead towards the end of the laying season, but the mortality does not approach that seen in turkey poults. It has also been observed that a large proportion of non-immune adult turkeys survive for many weeks in surroundings that would be promptly fatal to young poults.

RESULTS OF VARIOUS METHODS EMPLOYED IN THE TRANSMISSION OF BLACKHEAD.

Parenteral inoculation of infective liver lesions.—The production of infection by the injection of *Histomonas* into the tissues of various species of birds has been reported in an earlier paper (Tyzzer and Fabyan, 1920). Infection has followed subcutaneous, intramuscular, conjunctival, and intravenous inoculation, lesions appearing after an interval of several days at the site of the inoculation, except that lesions may occur in almost any of the internal organs following intravenous inoculation. Following successful breast inoculations in turkeys, secondary lesions regularly appear in the lungs and there is occasionally a further dissemination to other organs, especially the liver. In some species, such as the pigeon, inoculation results in lesions which develop actively for a time but soon regress.

Oral feeding of diseased tissues or caecal discharges and exposure to infected birds.—The experimental production of blackhead through the feeding of liver lesions has been reported in earlier publications (Tyzzer and Fabyan, 1922, Tyzzer and Collier, 1925). This method is rather uncertain, however, even though material is employed that is known to be fully infective when introduced in other ways. Apparently *Histomonas* may fail to survive the passage of the intestine in numbers sufficient to establish itself in the caeca. Continuous exposure to *Histomonas* carriers often eventually results in infection. Infection may sometimes also follow the exposure of healthy birds to acutely diseased ones, through the ingestion of food freshly contaminated with infective discharges (Tyzzer and Collier, 1925). *Histomonas* culture which, when fed orally to one of the series of chickens listed in Table I, failed to produce infection, caused infection when introduced into other chickens by rectal injection. The results of feeding chickens with diseased tissues, caecal discharges, or cultures of *Histomonas*, or of exposing them to carriers are summarized in Table I. (In this and all following tables, "C" before the bird number signifies young chicken; "T," young turkey; "K," killed; "D," died; and "Typical blackhead," histomoniasis with both caecal and liver lesions.)

Rectal inoculation of infective materials.—As first shown by Browne (1922) and later by Hall and Schillinger (1923), fluid introduced into the cloaca of the chicken is commonly passed into the caeca. Advantage is taken of this physiological response in the production of a type of blackhead infection which corresponds very closely with that which

TABLE I.
INGESTION OF INFECTIVE MATERIAL AND EXPOSURE TO CARRIERS.

BIRD	INOCULATION	RESULT
C 7221	Jan. 26, 1924. Fed suspension of diseased caecum.*	No infection
C 7422 C 7423 C 7424 C 7425 C 7426	From Apr. 9, 1925, in cage with two chicken carriers.	May 18. <i>Histomonas</i> present in discharges. May 15. Numerous <i>Histomonas</i> in discharges. May 15. <i>Histomonas</i> present in discharges. May 15. Few <i>Histomonas</i> in discharges. May 15. Numerous <i>Histomonas</i> in discharges.
C 7583	From Dec. 5, 1925, in cage with a chicken carrier.	K. Dec. 16. Typical blackhead.
C 7390 C 7391	April 9, 1925. Fed caecal discharges of chicken carrier.†	Apr. 13. <i>Histomonas</i> in discharges. Apr. 15. <i>Histomonas</i> and red blood corpuscles in discharges.
C 8464 C 8465 C 8466 C 8467 C 8468 C 8469	Jan. 5, 1932. Fed <i>Histomonas</i> culture.‡	No infection No infection No infection No infection No infection No infection

*A control bird rectally injected with a portion of the same material showed *Histomonas* with blood and mucus in caecal discharges seven days later.

†A portion of this material kept for twenty-three days in 1.5% nitric acid failed to produce infection when fed to five chickens.

‡Other fractions of the same culture material injected rectally on the same date into a control series of six chickens produced infection in all six.

occurs in nature. Indeed rectal inoculation furnishes an easy and rather reliable method of transmitting infection to both turkeys and chickens. A suspension of ground liver lesions may be employed (Tyzzler and Collier, 1925), cultures of *Histomonas* (Drbohlav, 1924), or the discharges of experimentally infected carriers. Delaplane (1932) also succeeded in infecting young turkeys and chickens reared under the conditions prescribed in our previous papers (Tyzzler and

Fabyan, 1922, and Tyzzer and Collier, 1925) by the rectal injection of diseased tissues and in one case by the rectal injection of *Histomonas* culture. It is thought that the inoculum is retained rather better in birds that have fasted overnight than in those that are fully fed. The data furnished in Table II will serve to illustrate the results obtained by the rectal injection of young chickens and turkeys with either the caecal discharges of carriers or cultures of *Histomonas*. While such inoculations are in general successful, it should not be concluded that infection invariably follows the rectal injection of *Histomonas*. It will be shown elsewhere that failure may result from conditions in the caeca unfavorable to the establishment of *Histomonas* or from failure to retain the injected material sufficiently long for it to pass into the caeca, as well as from the noninfectivity of materials injected.

Ingestion of Heterakis gallinae eggs.—It was first shown by Graybill and Smith (1920) that blackhead may follow the feeding of embryonated *Heterakis* eggs to young turkeys. Similar but more adequately controlled experiments carried out by Tyzzer and Fabyan (1920) furnish data indicating that the infective agent is carried within the worm egg. The infectivity of soil from a henyard containing large numbers of *Heterakis* eggs was also demonstrated by the latter authors in the occurrence of blackhead in thirty-one of thirty-two turkeys exposed, the only failure being in a turkey previously subcutaneously inoculated, and thus probably having some degree of immunity. The results of the experimental exposure of additional series of turkeys to henyard soil under laboratory conditions are furnished in Table III. Thus in a total of forty-nine young turkeys exposed to henyard soil, forty-seven have developed blackhead. The single failure in the series here reported showed no *Heterakis*. The number of worms is small in several of the turkeys showing typical blackhead, but with the obstruction of the caeca with cores of exudate, a large proportion of the caecal worms are destroyed.

Since the earlier experiments, a considerable amount of additional data has accumulated which furnishes rather convincing evidence of the transmission of blackhead through the agency of the egg of the caecal worm. In the absence of microscopic demonstration, various additional procedures have been resorted to in order to determine whether transmission results from the presence of *Histomonas* within the worm egg or in associated material. It is customary to collect from chickens large numbers of adult *Heterakis* which are thoroughly

TABLE II.
RECTAL INJECTION OF INFECTIVE MATERIALS.

BRD	INOCULATION	RESULT
C 7269 C 7270 C 7271 C 7272 C 7273 C 7274 C 7275 C 7276	March 15, 1924. Rectally injected with cultures of <i>Histomonas</i> .	K. Mar. 23. Typical blackhead. K. Apr. 14. A carrier. K. Mar. 28. Scarring of liver and caeca. K. Apr. 2. Scarring of liver and caeca, a carrier. K. Apr. 4. Scarring of liver and caeca, a carrier. D. Mar. 21. Typical blackhead. Carrier state maintained as late as July 26. K. Mar. 22. Typical blackhead.
C 7281 C 7282 C 7283 C 7284 C 7285 C 7286 C 7287 C 7288	April 2, 1924. Rectally injected with caecal discharges of a carrier of seventy-six days standing.	K. Apr. 3. Infection. <i>Histomonas</i> present. K. Apr. 4. Infection. <i>Histomonas</i> numerous. K. Apr. 5. Infection. <i>Histomonas</i> numerous. K. Apr. 6. Infection. <i>Histomonas</i> numerous. K. Apr. 7. Early typical blackhead. K. Apr. 8. Early typical blackhead. K. Apr. 11. Typical blackhead. K. Apr. 14. Late typical blackhead.
C 7301 C 7302	April 21, 1924. Rectally injected with <i>Histomonas</i> cultures.	K. Apr. 24. Infection. <i>Histomonas</i> numerous. K. Apr. 26. Caecal blackhead.
T 7304 T 7305 T 7306 T 7307 T 7308 T 7309 T 7310 T 7311	May 28, 1924. Rectally injected with <i>Histomonas</i> culture.	D. May 30. Infection. <i>Histomonas</i> few. D. May 30. Infection. <i>Histomonas</i> few. D. May 30. Infection. <i>Histomonas</i> few. D. May 30. Infection. <i>Histomonas</i> few. D. May 31. Infection. <i>Histomonas</i> few. K. June 4. Infection. <i>Histomonas</i> numerous. K. June 11. Typical blackhead.

TABLE II—(Continued).
RECTAL INJECTION OF INFECTIVE MATERIALS.

BIRD	INOCULATION	RESULT
C 7313 C 7314 C 7315	March 5, 1924. Rectally injected with <i>Histomonas</i> culture.	Carrier state established and continued up to July 28, when all three were employed for testing influence of drugs on <i>Histomonas</i> .
T 7317 T 7318	July 28, 1924. Rectally injected with <i>Histomonas</i> culture.	D. Aug. 4. Caecal blackhead. D. July 31. Infection. <i>Histomonas</i> numerous.
C 7326 C 7328	July 31, 1924. Rectally injected with caecal discharge of carrier.	K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present.
C 7329 C 7330 C 7331 C 7332 C 7333 C 7334	July 31, 1924. Rectally injected with <i>Histomonas</i> culture.	K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present. K. Sept. 8. Infection. <i>Histomonas</i> present.
T 7341* T 7342* T 7343† T 7344† T 7345 T 7346	Aug. 23, 1924. Rectally injected with <i>Histomonas</i> culture.	{ Aug. 25. <i>Histomonas</i> present, obtained in culture. K. Aug. 30. No gross lesions of blackhead. D. Aug. 30. Caecal blackhead with cores. D. Sept. 19. Chronic, typical blackhead. D. Sept. 2. Typical blackhead. D. Sept. 2. Typical blackhead. K. Aug. 30. Early typical blackhead.

*Naganol injected once prior to, and on two occasions after inoculation.
†Turpentine administered by mouth daily after inoculation,—the other two poultis served as untreated controls.

TABLE III.
INGESTION OF HENYARD SOIL.

BIRD	INOCULATION	RESULT	Heterakis
T 7515*	Aug. 17, 1925. Henyard soil placed in cage.	K. Aug. 31. Typical blackhead.	42
T 7516*		K. Aug. 31. Typical blackhead.	15
T 7517*		K. Sept. 2. Caecal blackhead.	23
T 7518*		K. Sept. 2. Typical blackhead.	82
T 7519*		K. Sept. 2. Caecal blackhead.	71
T 7520*		K. Aug. 25. Typical blackhead.	30±
T 7521		K. Aug. 25. Typical blackhead.	Numerous
T 7522		K. Aug. 31. Typical blackhead.	21
T 7523†	Jan. 5, 1927. Soil that had been exposed to freezing and thawing of winter weather without additional contamination for two months preceding, added to food and scattered in cage.	K. Oct. 1. Healed blackhead. Extensive scarring of liver and caeca.	11
T 7787		K. Jan. 19. Typical blackhead.	Numerous
T 7788		K. Jan. 20. Typical blackhead.	
T 7789		K. Jan. 21. Caecal blackhead.	Moderate numbers
T 7790		K. Jan. 19. Typical blackhead.	1 (dead)
T 7791		K. Jan. 22. Caecal blackhead.	Few
T 7792		K. Feb. 1. Caecal blackhead.	2
T 7793		K. Feb. 1. No infection.	Moderate numbers
T 8094	Jan. 8, 1930. Henyard soil placed in cage.	K. Jan. 25. Typical blackhead.	101

* "Avisepstone" supplied in drinking water throughout experiment.
† Stovarsol injected intravenously Sept. 10, 11, 12 and 14.

washed and then stored in Petri dishes in a shallow layer of 1.5 per cent nitric acid until the eggs become embryonated. This storage in acid tends to sterilize all material external to the egg shell, and even after only three days' exposure to the acid, worms washed and broken up on various media have failed to furnish any bacterial growth. There is no evidence of any form of *Histomonas* that is capable of withstanding the direct action of the dilute acid. Other materials such as diseased tissue and discharges containing *Histomonas* but no *Heterakis*, after treatment with the acid, have failed to produce infection when fed to normal birds (Table IV). The demonstrable

TABLE IV.

INOCULATION OF DISEASED TISSUES, EXUDATE AND DISCHARGES OF
HETERAKIS-FREE CARRIERS AFTER STORAGE IN 1.5 PER CENT NITRIC ACID.

BIRD	INOCULATION	RESULT
T 7132	Sept. 20, 1923. Fed and rectally injected with a mixture of ground liver and caecal lesions and caecal cores from three cases of blackhead, in 1.5 per cent nitric acid for thirteen days.	No infection
T 7133		No infection
T 7134		No infection
T 7138		No infection
T 7139*		No infection
T 7140*		No infection
T 7171	Sept. 15, 1923. Fed and rectally injected with ground caecal cores from two cases of blackhead, in 1.5 per cent nitric acid for five days.	No infection
T 7172		No infection
C 7415	May 2, 14 and 16, June 1, 3 and 9, 1925. Fed caecal discharges of carriers kept in 1.5 per cent nitric acid for 23, 8, 2, 4, 8, 2 and 1 days respectively.	No infection
C 7416		No infection
C 7417		No infection
C 7418		No infection
C 7419		No infection

* Similarly reinoculated with same material on Sept. 21 and 22.

infectivity for normal birds of some of the materials employed in the experiments above tabulated before treatment with acid, does not constitute an adequate control, for there is no question as to the possibility of transmitting infection by appropriate inoculation of non-resistant forms of *Histomonas*. The object in this case was to obtain evidence as to the presence of resistant forms in materials other than *Heterakis* eggs.

TABLE V.
INGESTION OF ACID-TREATED *Heterakis* MATERIAL BEFORE AND AFTER EMBRYONATION
OF THE EGGS, AND ALSO OF ACID-TREATED *Heterakis* MALES.

BIRD	INOCULATION	RESULT	<i>Heterakis</i>
T 7188	Oct. 6 and 8, 1923. <i>Heterakis</i> material of Oct. 4 and 5, eggs non-embryonated, fed and rectally injected.	D. Oct. 12. No infection.	0
T 7189		D. Oct. 23. No infection.	0
T 7190		D. Oct. 12. No infection.	0
T 7191		D. Oct. 12. No infection.	0
T 7192		K. Nov. 27. No infection.	0
T 7193	Oct. 20 and 22, 1923. Fed <i>Heterakis</i> material of Oct. 4 and 5, eggs embryonated.	D. Nov. 3. Typical blackhead.	Hundreds
T 7194		D. Nov. 6. Typical blackhead.	Hundreds
T 7195		D. Nov. 9. Typical blackhead.	100 ±
T 7196		D. Nov. 9. Typical blackhead.	Numerous (some dead)
T 7197		D. Nov. 8. Typical blackhead.	150 ±
C 7395	April 16, 1925. Fed <i>Heterakis</i> material of April 13, eggs non-embryonated.	K. Apr. 22. No infection.	0
C 7396		K. May 1. No infection.	0
C 7397		K. May 1. No infection.	0
C 7398		K. May 1. No infection.	0
C 7399		K. May 1. No infection.	0
C 7400		K. May 1. No infection.	0
C 7401		K. May 1. No infection.	0
C 7402		K. May 1. No infection.	0
C 7407	May 1, 1925. Fed <i>Heterakis</i> material of April 13, eggs embryonated.	K. May 9. Caecal blackhead.	Numerous
C 7408		K. May 11. No infection.	Very numerous
C 7409		K. May 11. Caecal blackhead.	Small numbers
C 7410		K. May 14. No infection.	815
C 7411		K. May 14. Microscopic focus.	7
C 7412		K. May 14. No infection.	589
C 7413		K. May 11. Typical blackhead.	Few
C 7414		K. May 14. Microscopic focus.	66

TABLE V—(Continued).
INGESTION OF ACID-TREATED *Heterakis* MATERIAL BEFORE AND AFTER EMBRYONATION
OF THE EGGS, AND ALSO OF ACID-TREATED *Heterakis* MALES.

Bird	INOCULATION	RESULT	<i>Heterakis</i>
T 7450	July 1, 1925. Fed <i>Heterakis</i> material of June 26; July 29, fed <i>Heterakis</i> material of July 25; Aug. 28, fed <i>Heterakis</i> material of Aug. 24, eggs in each instance non-embryonated.	No infection.	0
T 7451		No infection.	0
T 7452		No infection.	0
T 7453*		No infection.	0
T 7454		No infection.	0
T 7455		No infection.	0
T 7456		No infection.	0
T 7457		No infection.	0
T 7479	July 13, 1925. Fed <i>Heterakis</i> material of June 26; Aug. 6, fed <i>Heterakis</i> material of July 25; Sept. 4, fed <i>Heterakis</i> material of Aug. 24, eggs in each instance embryonated.	Sept. 20. Typical blackhead.	200 ±
T 7480		D. Sept. 20. Typical blackhead.	50 ±
T 7481		D. Sept. 20. Typical blackhead.	100 ±
T 7482		D. Sept. 21. Typical blackhead.	8
T 7483		K. Sept. 21. Typical blackhead.	5
T 7484		D. Sept. 25. Typical blackhead.	15
T 7485		K. Nov. 7. Typical blackhead.	25
T 7486	Sept. 18, 1925. Each fed 1/8 of suspension of 346 female <i>Heterakis</i> of Aug. 29, eggs embryonated.	D. Oct. 5. Typical blackhead.	Very numerous Not examined 70
T 7487		D. Sept. 24. No gross lesions.	
T 7488		D. Oct. 8. Typical blackhead.	
T 7489	Sept. 18, 1925. Each fed 1/4 of suspension of 174 male <i>Heterakis</i> of Aug. 29.	K. Oct. 26. No infection.	9†
T 7490		K. Oct. 26. No infection.	2†
T 7491		K. Oct. 26. No infection.	0
T 7492		K. Oct. 26. No infection.	0

* Killed before third experimental feeding.

† The birds of this group had been fed non-embryonated *Heterakis* eggs on July 13 and August 6, and possibly reingested eggs that passed through the intestine some of which may have become embryonated on the cage bottom. It is also possible that occasional free eggs adhered to the males and were thus ingested at the September 18 feeding.

TABLE V—(Continued).
INGESTION OF ACID-TREATED *Heterakis* MATERIAL BEFORE AND AFTER EMBRYONATION
OF THE EGGS, AND ALSO OF ACID-TREATED *Heterakis* MALES.

BIRD	INOCULATION	RESULT	<i>Heterakis</i>
T 7486 T 7487 T 7488 T 7489 T 7490 T 7491 T 7492 T 7493	July 13, 1925. Fed <i>Heterakis</i> material of July 9, ova non-embryonated.	No infection, survived. No infection, survived. No infection, survived. No infection, survived. No infection, survived. No infection, survived. No infection, survived.	
T 7507 T 7508 T 7509 T 7510 T 7511 T 7512 T 7513 T 7514	July 20, 1925. Fed <i>Heterakis</i> material of July 9, ova embryonated.	July 29. No gross lesions. D. Aug. 1. Typical blackhead. D. Aug. 4. Typical blackhead. D. Aug. 5. Typical blackhead. D. Aug. 6. Typical blackhead. D. Aug. 6. Typical blackhead. K. Aug. 6. Typical blackhead. D. Aug. 7. Typical blackhead.	13 Few 10± 1 4 4 1 1 1

TABLE VI.
SUMMARY OF EXPERIMENTS IN WHICH EMBRYONATED *Heterakis* OVA
HAVE BEEN FED TO YOUNG TURKEYS AND CHICKENS.

NO. OF BIRDS	INFECTED	NOT INFECTED
2 Turkeys	2	0
2 "	1	1
5 "	5	0
7 "	7	0
3 "	2	1 (no microscopic exam.)
8 "	0	8
5 "	5	0
8 "	7	1 (no microscopic exam.)
1 "	0	1
1 "	1	0
Total 42 Turkeys	30	12 (two not examined microscopically)
19 Chickens	12	7 (no microscopic exam.)
6 "	6	0
8 "	0	8
8 "	5	3
10 "	6	4
10 "	10	0
4 "	2	2 (no microscopic exam.)
3 "	0	3
1 "	1	0
1 "	1	0
4 "	0	4
4 "	4	0
4 "	0	4
2 "	2	0
2 "	0	2
2 "	0	2
2 "	0	2
2 "	2	0
Total 92 Chickens	51	41

Even more conclusive are the results obtained by feeding samples of *Heterakis* material, some before and some after the eggs have become embryonated and hence hatchable. Numbers of *Heterakis*

males from the same source and subjected to the same treatment as the ova-containing females which produce blackhead, also have failed to give rise to infection when ingested by normal birds. The experiments included in Table V illustrate the points in question. These results indicate that infection following the feeding of *Heterakis* material is dependent on the hatching of the eggs of this worm in the alimentary tract of the bird.

Not all samples of *Heterakis* ova carry blackhead infection, and in fact a blackhead-free strain of the worm has been propagated in chickens for several generations. It seems probable that only a small proportion of the adult female *Heterakis* carry infection, as indicated by the no more than occasional invasion by *Histomonas* of the intestinal epithelium of young worms, and perhaps only a small percentage of the eggs of those are infected. Doubtless the proportion of infective worms will vary widely in various samples of material. Thus, omitting experiments with the strain of *Heterakis* known to be blackhead-free and those of previously published experiments, embryonated eggs have been fed in ten experiments to forty-two turkeys, and in eighteen experiments to ninety-two chickens, with the results as summarized in Table VI.

TYPES OF CAECAL DISEASE TO BE DIFFERENTIATED FROM BLACKHEAD.

Helminthic typhlitis.—Large numbers of *Heterakis gallinae* developing in the caeca of young chickens produce *per se* a pathological condition which is usually characteristic and readily differentiated from either caecal blackhead or coccidiosis. When *Histomonas*-free *Heterakis* material is employed, it is only in rare cases that exudate is produced in such amount as to lead to the confusion of this condition with either of these diseases. Very early or slight infections in either blackhead or coccidiosis may be recognized only by microscopic study of the caecal mucosa.

After the hatching of the *Heterakis* eggs in the bird's intestine, the young larvae penetrate the epithelium of the caecal glands, a point which apparently escaped the attention of both Graybill (1921) and Uribe (1922) in their studies on the development of this parasite. In stained sections, young worms are found in the epithelium, coiled around the lumina of the glands (Fig. 2). While, at this stage, the head of the young worm may occasionally break through the epithelium, none has been found either immediately beneath the epithelium or in the underlying tissue. There is no appreciable inflammatory

reaction in the vicinity of the young worm. The only demonstrable injury consists of the separation and flattening of the epithelial cells through the pressure of the worm.

In the course of their subsequent development, the worms literally grow out of the glands as noted by Uribe, and eventually come to lie free in the sulci between the folds or elevations of the caecal mucosa. It is at this stage of development that the most pronounced inflammatory reaction has been noted. If the caeca of a young chicken killed from ten to twelve days after ingestion of embryonated *Heterakis* eggs are laid open, the caecal mucosa often shows a deep red coloration of its numerous elevations due both to local congestion and to the occurrence of punctate hemorrhages (Fig. 1). In this case examination by means of a lens will reveal swarms of young worms lying mostly in the sulci between the elevations of the mucosa. In the more severe cases, there is a small amount of blood-tinged fluid on the surface of the mucosa or the latter is covered with a delicate membrane of exudate.

A study of stained sections shows that, in glands occupied by worms, the epithelium is furrowed by the sharp-edged, lateral flanges of these parasites (Fig. 3). As the worm becomes too large for the gland, its anterior extremity often remains inserted in the gland (Fig. 4) and occasionally, partially grown larvae pierce the epithelium and are found extending through the mucosa without special relation to the glands. This deep penetration appears to take place more frequently when the mucosa is diseased, especially when infiltrated with *Histomonas*. In one case, a chicken *Histomonas*-carrier, killed ten days after being fed large numbers of embryonated *Heterakis* eggs, had the blind end of the caeca filled with exudate which extended also in a layer over the greater part of the remaining mucosa. In this case, *Histomonas* could not be demonstrated either in the exudate or the caecal mucosa, but was present in the intestinal epithelium of many of the young worms. In the presence of large numbers of growing worms, the epithelium in the depths of the sulci may be not only damaged but destroyed (Fig. 5), while fibrinous or hemorrhagic exudate accumulates in considerable amount. There is also extensive cellular infiltration of the tissues in the neighborhood of the defects.

Thus a pathological condition occurs in the caeca of chickens at a certain stage in the development of *Heterakis*. Apparently, under certain circumstances, the presence of numbers of the worms may excite a more marked response on the part of the tissues, with an

excess of exudate. Owing to lack of appropriate material, it is not known to what extent the caeca of young turkeys are damaged through the development of *Heterakis* larvae.

Nonspecific typhlitis of newly hatched chickens and turkeys.—Both chickens and turkeys dying within the first week of life not infrequently show opaque, whitish or yellow-tinged caecal cores, usually of rather firm consistence. It appears important to call attention to this condition, since, without study of stained sections of the caecal wall, it may be confused with blackhead infection.

While the etiology of this form of typhlitis is not wholly understood, it would appear that abnormal conditions arising from functional failure outweigh the inflammatory element in the process and the latter when present may very well represent the reaction of the caeca to a mass of bacteria-containing residuum which cannot be expelled readily. Since fluid is rapidly absorbed in the caeca as shown in observations made in the course of coccidiosis investigations (Tyzzar, Theiler and Jones, 1932), any shortage in the supply of fluid coming to the caeca results in an inspissation of the caecal contents. In cases of typhlitis of the type under discussion, some of the cores are composed in part of fecal material and in part of opaque material of caseous consistence, some cores being firm and tough, others more soft and friable. Such cores are in no instance adherent to the caecal wall.

Stained sections have revealed no more than slight inflammation of the caecal wall and nothing of etiological significance. The epithelium is usually found to be intact. Apparently the cores may be derived from a deposit of non-cellular exudate on a nucleus of inspissated fecal material and mucous secretion. Complete obstruction occurring in the first days of life is often sufficient to cause death. Thus the occurrence of caecal cores in birds dying during the first week of life can not be accepted as evidence of blackhead, and the claim of transmission of the infection through the turkey's egg on the basis of such data should not be accepted. The demonstration of *Histomonas* and the disease process with which it is associated is necessary for diagnosis.

Caecal coccidiosis.—The lesions of caecal coccidiosis are usually distinguishable from those of other diseases affecting the caeca of the chicken or the turkey, either by the mottled appearance of the caecal wall or by the presence of frank hemorrhage. Even mild cases of this type of infection should be recognized without difficulty on study of stained sections.

SUMMARY

Attention is called to the importance, in the investigation of blackhead, of employing birds reared in the laboratory and kept free of protozoa.

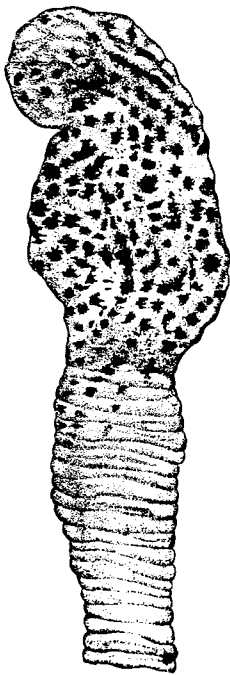
Methods of producing experimental histomoniasis are outlined. The feeding of materials containing *Histomonas* to young chickens and turkeys may produce blackhead infection but is less reliable as a method than the rectal injection of such materials. Contaminated soil is shown to be an important source of blackhead infection, its infectivity apparently being due to the presence of numbers of embryonated eggs of *Heterakis gallinae*. The ingestion of male *Heterakis* or non-embryonated *Heterakis* eggs has not produced blackhead, but the ingestion of the embryonated eggs of this worm is frequently followed by this infection. Thus while the protozoön has not been recognized microscopically within the worm egg, the experimental evidence indicates its presence there, and further that the hatching of the egg is necessary for its release in the bird's intestine. No resistant stage of *Histomonas* has been recognized and the exposure of discharges and diseased tissues containing *Histomonas* to 1.5 per cent nitric acid, the reagent utilized for the storage of *Heterakis* material until the eggs in the latter become embryonated, renders such materials non-infective.

Attention is called to other types of typhlitis occurring in young chickens and turkeys, which are to be differentiated from blackhead infection. The common occurrence in chickens and turkeys of a form of typhlitis of unknown etiology and characterized by the formation of cores obstructing the caeca is reported. This is found at a very early age and should not be confused with blackhead infection. Caecal coccidiosis is readily differentiated from blackhead by the study of the caecal mucosa in stained sections.

PLATE I.

FIG. 1. A caecum of a seventeen-day old chicken fed embryonated *Heterakis* eggs ten days prior to being killed. The caecum has been laid open by longitudinal incision, to show the mucous surface. The elevations of the mucosa of the saccular portion present numerous deep red petechiae (represented in the dark blotches of the drawing) due to minute hemorrhages and congestion. Swarms of small developing *Heterakis* were found in the depressions of the mucosa, three hundred and twenty-eight being counted from one caecum. $\times 2$.

PLATE I



1

Helminthic typhlitis.—Hemorrhagic petechiae in caecal mucosa of young chicken. X 2.

PLATE II.

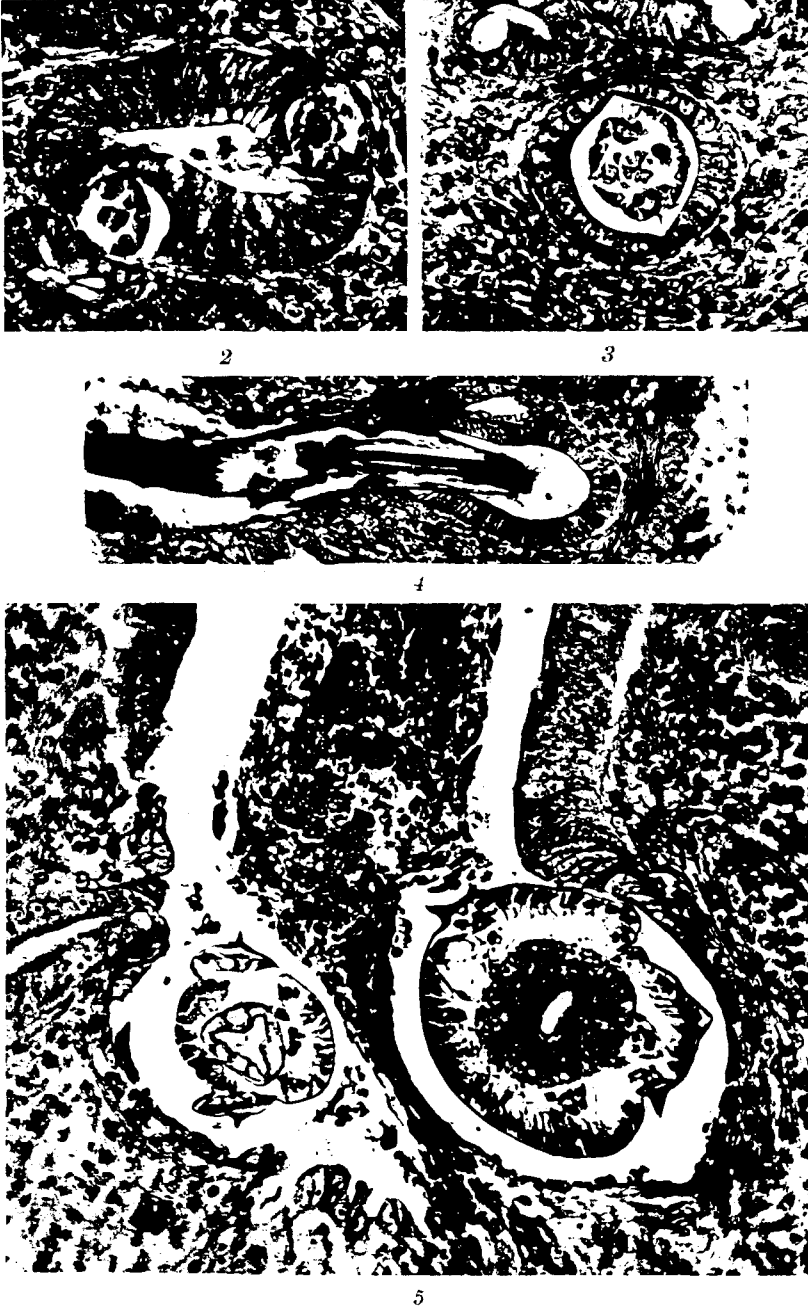
FIG. 2. A caecal gland of a young chicken with a young Heterakis larva coiled in epithelium and twice sectioned. $\times 390$.

FIG. 3. A somewhat more developed larva, shown in cross section, with body extending free in the lumen of the distended gland. The gland epithelium is furrowed by the lateral cuticular flanges of the worm. From a young chicken eight days after feeding embryonated Heterakis eggs. $\times 390$.

FIG. 4. Heterakis larva, with anterior extremity inserted into a caecal gland, the fundus of which is apparent to the right. From a chicken ten days after the ingestion of Heterakis eggs. $\times 195$.

FIG. 5. Two worms lying deep in a sulcus between elevations of caecal mucosa, shown in cross section. There is local destruction of epithelium, infiltration of adjacent tissue and an outpouring of exudate which in this case filled the blind ends of the caeca. From a chicken ten days after ingestion of Heterakis eggs. $\times 390$.

PLATE II



Successive developmental stages of *Heterakis* larvae in the caecal mucosa. Photomicrographs.

III. *HISTOMONAS MELEAGRIDIS* IN THE AVIAN CARRIER, IN CULTURE AND IN THE CAECAL WORM, *HETERAKIS GALLINAE*.

The morphology of the protozoön of blackhead as found in the tissues of diseased turkeys has already been considered rather fully in papers by Smith (1895 and 1915) and by the author (1919). The tissue-inhabiting form of this organism has the general appearance of a small amoeba, and in fact was classified tentatively by Smith as of the genus *Amoeba*. In seeking to determine the method of multiplication of the protozoön, I found that it presented regularly an extra-nuclear structure from which division centers originated and that in the course of nuclear division, a long coarse fibril or "paradesmose" was formed. A large proportion of nondividing forms showed intracytoplasmic fibrils suggestive of flagella extending from the extra-nuclear structures. Further evidence of the flagellate nature of this protozoön was obtained by the study of its movements, at temperatures ranging from 38° to 40° C., in preparations made from liver lesions. It was observed that there was not only a change of shape and a formation of various types of pseudopodia, but also that rhythmic, rotatory movement developed with the appearance of a rudimentary flagellum. Consequently it was obvious that the blackhead protozoön should be reclassified and thus the genus *Histomonas* was created (Tyzzer, 1920). The study of lesions taken at various stages of infection had shown differences in the morphology of the protozoön, *Histomonas meleagridis*, which appeared to have a definite relation to the stage of infection and the reaction of the host tissues. Thus organisms found in the earliest infections or where the tissue was being actively invaded tended to be more drawn out, extending through the interstices of the tissues, and were notably basophilic in their staining affinities; those forms that were found in somewhat older portions of the infected area were large, rounded, closely packed and showed little affinity for stains, their clear hydropic appearance causing them to be readily overlooked; and finally small, dense, rounded forms were found late in the disease process. The last mentioned type of *Histomonas* shows a somewhat granular cytoplasm which stains intensely, especially with eosin, often occurs in "nests" of from four to twelve or more individuals and is commonly found included within host cells, many of which assume the character of foreign-body giant cells. These small dense, deeply staining forms constitute a much more prominent feature in stained sections of

blackhead lesions than the two types previously described, but structural similarities and the occurrence of transitional forms make it clear that we are dealing with a single species of protozoön.

At this stage of investigation, the exact mode of transmission of the infection was not understood. The small dense forms of *Histomonas*, especially those that occur within giant cells, commonly show a refractive limiting membrane, and it was suggested that these might represent resistant forms serving to transmit the infection to normal hosts. Support for this view was found in the occurrence of considerable numbers of giant cells containing many such forms, free in the bile ducts of diseased livers. In view of what has since been determined concerning the nature of *Histomonas* and its transmission, the above hypothesis now appears unlikely and probably erroneous. The dense, limiting membrane appearing in the intracellular forms of *Histomonas* evidently represents its reaction to the engulfing cell rather than a product of cyclic development and it does not appear probable that the discharge of organisms in the bile plays a significant role in the transmission of the infection.

In considering the question of transmission, the intestinal discharges from acute cases of blackhead in turkeys have been studied. *Histomonas* is not regularly demonstrable either in caecal discharges or in caecal contents during the active phase of the disease. In fact, on account of the complete caecal obstruction which occurs in severe cases, no caecal discharges are obtainable for long periods, and even when the caeca are not involved throughout, the changes in the caecal contents appear to render this material unfavorable for the maintenance of the organism. Occasionally, however, a thin, blood-tinged discharge may show numbers of large refractive forms of *Histomonas* similar to those found in the tissues. Obviously, direct transmission of infection from diseased to normal birds may only be expected to take place when the protozoön is present in the discharges.

Flagellated forms of *Histomonas* were first recognized free in the lumen of the caecum in a number of experimental turkey poults some of which had survived for twenty-two days after inoculation (Tyzzar and Fabyan, 1922). These birds were employed in our first adequately controlled experiment, planned to test out the production of blackhead by feeding embryonated *Heterakis* ova as reported by Graybill and Smith (1920). The poults used in this experiment were incubator-hatched and rigid precautions were taken to keep them isolated and unexposed to any form of infection other than that intentionally

introduced. Three of these poults when killed twenty-two days after being fed *Heterakis* eggs showed large numbers of a rounded protozoön exhibiting a type of rhythmic motility quite unlike that of the common caecal flagellates encountered in non-isolated lots of turkeys. Attention should be called to the fact that all three poults in which flagellated organisms were observed, showed no caecal cores although areas of the caecal wall were inflamed and liver lesions were present in each. In a later experiment, similar flagellated forms were noted in a young turkey dying of blackhead twenty-eight days after being fed embryonated *Heterakis* eggs. The organisms in question were at the time considered to represent the flagellate phase of *Histomonas* (Tyzzer and Fabyan, 1922).

From this observation, it was natural to look for such flagellated forms in birds that commonly recover from blackhead, i. e. in chickens (Smith and Graybill, 1920), and from the subsequent study of infections in the latter, the carrier condition came to be recognized (Tyzzer, 1924), in which *Histomonas* may be maintained for an indefinite period through its multiplication in the caecal contents. The possibility of growing the flagellated form of *Histomonas* from the caecal discharges of the carrier was first demonstrated in this laboratory by Boeck employing the Locke-egg-serum medium utilized in the cultivation of *Endamoeba histolytica* (Boeck and Drbohlav, 1925), and a further study of its growth was continued by Drbohlav (1924). All previous attempts to cultivate this organism from diseased tissue had failed. Some encouragement had been derived from the great numbers of the protozoön sometimes present after twenty-four hours in the culture tube, but these almost invariably had disappeared before the end of the third day. Further attempts to culture *Histomonas* directly from liver lesions have thus far been unsuccessful. The experimental production of carriers thus paved the way for the propagation of *Histomonas* in vitro.

Although in the course of subsequent investigations on blackhead, a thorough acquaintance with the more important morphological and biological characters of the flagellated phase of *Histomonas* was acquired, the publication of an adequate description of such forms has been long delayed. On reporting the chicken as a carrier of *Histomonas*, the following abstract was published:—" *Histomonas* in its flagellated phase usually shows a single flagellum; motility pulsatile in type, occasionally large forms appear with several flagella. Both uniflagellate and multiflagellate forms show a great variety of amoe-

boid movement, ingest bacteria, cell fragments and small starch granules." (Tyzzer, 1924).

Flagellated forms of *Histomonas* are figured in Wenyon's Protozoölogy (1926), being here credited through some misunderstanding to Drbohlav, but drawn, as I have subsequently learned, from one of the stained films which I had personally prepared and furnished the latter author.* In Wenyon's discussion of the blackhead protozoön, which is otherwise quite satisfactory, it is unfortunate that a number of inaccuracies should occur such as a typographical error in the spelling of the specific name. Also, the statement that "Tyzzer, 1919 . . . returns to Theobald Smith's original view that the invading organism is actually an amoeba and that the disease is comparable to amoebic dysentery in man" is wholly without foundation and is contrary to my views. I pointed out in this publication that "It is evidently not related to parasitic amoebae of the genus *Entamoeba*," and also that "The presence of an extranuclear body and the character of the nuclear division which is similar to that which occurs in trichomonads suggests strongly that we are dealing with a species of flagellate." Jowett (1911) had long previously "confirmed" Hadley and Amison (1911) in the identification of the blackhead protozoön as a *Trichomonas* and had pictured aflagellate organisms with extranuclear granules. From the drawings illustrating this author's paper, it appears probable that he observed the extranuclear structure, and in fact in his discussion of the figure he speaks of the organism as a "binucleated" one. Although trichomonads and blastocysts were included as stages of the blackhead organism, the figure in question was described as drawn from a preparation of the caecal wall and illustrates the extranuclear granule in several organisms.

Since the tissue forms of *Histomonas meleagridis* have been described already (Smith, 1895 and 1915, and Tyzzer, 1919), and evidence presented by the latter author of their mode of multiplication through binary division, the present investigation will deal more

* Dr. Wenyon in a personal communication has kindly furnished information as to the labelling of the film utilized for his figures. Since this film bears my personal accession number, it is found that it was prepared from the caecal contents of a laboratory-reared, chicken carrier, fifty-six days old when killed on January 27, 1924. This bird was one of a group infected thirty-five days previously through the feeding of *Heterakis* ova that had been kept in a 1.5 per cent solution of nitric acid for a period of twenty-two days during which time embryonation had occurred.

especially with the morphological features and biological characteristics of this protozoön outside the tissue of its avian host.

SOURCES OF MATERIAL.

The caecal discharges of farm-reared birds are quite unsatisfactory for the study of the flagellate phase of *Histomonas*. The picture is usually confused by the presence of swarms of intestinal flagellates of various species, and parasitic amoebae are also frequently encountered as well as blastocysts in all stages of development. The most satisfactory material is derived from experimental infections in rigidly isolated, laboratory-reared birds. By the routine procedure described in the previous section which has been followed in this laboratory for a long period of years, large groups of birds are kept free of all parasitic protozoa for periods of several months, in fact as long as the requirements of the experiment demand. Accidental infections may occur, but are then readily recognized and conditions remedied. On the other hand, a sojourn of a very short time under farm conditions is all that is necessary for the acquisition of protozoan infections. Thus *Chilomastix* has been encountered in turkey poults that were kept for a day only in a brooder house that appeared immaculately clean.

Histomonas carriers.—Experimentally infected chickens kept under the regime of isolation already outlined, furnish the most favorable sources of the flagellate forms of *Histomonas*. In the chicken, the invasion of the tissues is usually of brief duration and with recovery the protozoön quite regularly succeeds in maintaining itself through multiplication in the caecal contents, in this way establishing the carrier state. In young turkeys, on the other hand, the infection is usually fatal within a brief period thus making only the aflagellate, tissue-forms of the protozoön available. However, the loss of pathogenicity of *Histomonas* in the course of long cultivation, a matter which has been reported briefly in another paper (Tyzzer, 1932), has made possible the use of young turkeys as well as chickens in the present investigation, since the carrier state is as readily established in the former as in the latter birds by the inoculation of an attenuated culture of the protozoön.

As already pointed out, young chickens and turkey poults may be infected with blackhead in various ways under laboratory conditions which exclude other infections as well as the common intestinal protozoa and usually blastocysts also.

(1) The oral feeding of materials containing *Histomonas*, such as liver lesions taken in the acute stage of the disease, or the caecal discharges of laboratory-infected birds (Tyzzler and Fabyan, 1922, Tyzzler and Collier, 1925), or *Histomonas* cultures, to laboratory-reared birds has furnished infection but this method is somewhat unreliable. Presumably many of the organisms are destroyed in the passage of the alimentary tract or those which survive may fail to establish themselves in the caeca.

(2) The rectal injection of materials containing *Histomonas* enumerated in the preceding paragraph furnishes a high percentage of successful results (Tyzzler, 1924, Tyzzler and Collier, 1925). The degree of success obtained varies, but on the whole the method is highly satisfactory. The protozoön is established in the caecum at once, commonly in such numbers that it may be found in the discharges within twenty-four hours and it may persist thereafter for an indefinite period. In two of the chicken carriers of which we have record, *Histomonas* persisted in the caecal discharges from October thirtieth, the time of inoculation, up to June twelfth, and June twenty-fifth, the respective dates upon which the two birds were killed, i. e. for periods of more than seven months. A daily examination of the caecal discharges also furnishes a valuable indication of what is taking place in the inoculated birds. Such discharges normally consist largely of bacteria and show very few cells. At the onset of inflammatory processes, leucocytes appear and the presence of red blood corpuscles is another indication of injury. If the caecal walls become extensively diseased and exudate accumulates, the caeca become occluded and the discharges cease to appear. With recovery, the mass of exudate is either loosened and discharged, or in some cases digested away, so that function is resumed, as shown by the reappearance of the caecal discharges. Thus by following the changes in the cell content of the caecal discharges of a series of inoculated birds, as well as the number and appearance of *Histomonas* present from day to day, and by killing some of the birds after appropriate intervals for the study of tissues, it is possible to follow step by step all stages of infection.

(3) Large numbers of mature *Heterakis gallinae*, preferably hundreds if collected from market chickens, may be kept in 1.5 per cent nitric acid in Petri dishes until most of the fertile eggs become embryonated, when they may be fed to young chickens or turkeys (Tyzzler and Fabyan, 1922, Tyzzler, 1926). A small number of worms

from certain birds may suffice. *Histomonas* seldom appears in the caecal discharges before the eighth day after feeding embryonated *Heterakis* eggs but isolated organisms have been observed earlier in some instances,—at the end of the sixth day in one case.

Cultures.—*Histomonas* is usually readily isolated from the caecal discharges of a laboratory-reared carrier in mixed culture with bacteria. Blastocysts when in large numbers in the caecal discharges seriously interfere with the isolation and continued cultivation of this protozoön. Young birds may be kept free of blastocysts by rearing them under the laboratory regime already outlined. The richer media originally used, such as the L. E. S. medium of Boeck and Drbohlav (1925), have been replaced by media which are less favorable to bacterial growth. Cultures on the medium now routinely employed are not only free from the offensive decomposition which occurs in egg media, but have the advantage of being much longer lived. The addition of a small amount of rice starch to the fluid of the culture, as advocated by Dobell and Laidlaw (1926) in the cultivation of *Entamoeba histolytica*, has proved of great value. When ordinary commercial rice flour is employed, it is made available for the protozoön through the action of the bacteria present which break the large starch grains into minute particles. Some of the refined rice starches which come finely ground appear to be quite as favorable for the cultivation of *Histomonas* as the coarser grades. While one of the strains now under cultivation was first isolated on the L. E. S. medium of Boeck and Drbohlav, the following medium has proved quite satisfactory, not only for the continuous culture of the organism, but also for its isolation from caecal discharges.

Agar 14 grams, sodium chloride 6 grams, and potassium acid phosphate (KH_2PO_4) 2.7 grams are dissolved in 900 c.c. tap water by heating in the autoclave. After allowing the agar to cool to 55°C ., the beaten white of one egg diluted with a small amount of water is added, and the mixture is then cooked in the Arnold sterilizer for 45 minutes, being taken out and shaken well every fifteen minutes during the process. After allowing the coagulated egg white to settle, the agar is filtered through cotton, adjusted to pH 7.2, passed through filter paper, tubed, autoclaved and stored until needed. To complete the preparation of the medium, the requisite number of tubes are heated in boiling water, slanted and a small amount (about the volume of a wheat grain) of fine rice starch sterilized by dry heat is added to each tube. Normal saline containing 5 per cent sterile horse serum is then added in sufficient amount to cover the slants. It has been

customary to add also a small amount of dry sterilized animal charcoal to the fluid of each tube, this not being necessary but apparently increasing the longevity of the culture.

The life of the individual culture may be prolonged by adding small amounts of starch at intervals. As the starch disappears, the protozoa become fewer and less healthy, as indicated by their granular and shadowy appearance, but with the renewal of the starch, they regain their bright hyaline appearance and increase in number. The nature of the bacteria associated with *Histomonas* on its isolation from caecal material is of considerable importance in its subsequent propagation. Some cultures are obtained in which the starch is rapidly destroyed, thus eliminating the food supply of *Histomonas*. In one isolation which furnished an abundance of protozoa in the first tube inoculated, the increase in the rate of starch destruction in successive transfers rendered it impracticable, if not impossible, to maintain the strain in cultivation. On the other hand, some isolations have furnished optimum conditions for the propagation of *Histomonas*, the starch on account of the slowness of its destruction being available for a long period. Thus, one strain of *Histomonas* maintained in culture at present often survives for more than three weeks in the test tube without addition of starch. Intermediate between these extremes are cultures, the transfers of which become extremely rich in *Histomonas* for a time, but are nevertheless short-lived.

The protozoön usually eventually dies out in the culture tube, even if the supply of starch is kept up, probably from the gradual accumulation of products of bacterial growth. Starvation is thus not the only lethal condition arising in the culture tube. It has been found that the products of degeneration and death of the protozoön itself have no appreciable deleterious effect upon its growth. Thus a culture which for a time is extremely rich in organisms and later as the result of starch starvation shows only a few, degenerated forms may be fully revived by the addition of starch. *Histomonas* will survive a marked concentration of the medium through the evaporation that occurs during weeks of incubation. Thus the fluid may be reduced by one-half its original volume, or to one-fourth the total medium. The capacity of the organisms for survival in culture when starch and fluid are renewed is illustrated by the following.—A tube inoculated on March 10, 1930 showed large numbers of *Histomonas* a week later. By maintaining the supply of starch and by adding at intervals water, saline, or saline with serum to offset evaporation, the culture

was maintained in a single tube until January 24, 1931, i. e. for over ten and one-half months. On one occasion a considerable amount of fluid was removed from the tube and replaced by fresh saline with 5 per cent serum, the only material otherwise removed being small amounts of sediment taken at long intervals in order to test the viability and infectivity of the culture. Thus a much greater longevity has been obtained in *Histomonas* cultures than has been the case with other parasitic protozoa grown in association with bacteria.

It is apparent that the agar, serum-saline, starch medium that is now employed as a matter of routine is not *per se* ideal for the cultivation of *Histomonas*, but is rendered favorable by the action of bacteria. It has been repeatedly noted that when tubes of this medium are inoculated with a generous amount of sediment rich in *Histomonas*, it is difficult to demonstrate the protozoön twenty-four hours later. Concomitant with the growth of the bacteria, the sediment shows after a few days great numbers of *Histomonas*. It is hoped that further studies will furnish more exact information as to the cultural requirements of this organism. The loss of virulence in strains of *Histomonas*, which has taken place under long cultivation will be discussed in another paper.

The larvae of the caecal worm.—*Histomonas* has also been found in the gut of the larvae of *Heterakis gallinae*, but thus far it has not been demonstrated elsewhere in this worm although blackhead infection may be experimentally transmitted to chickens and turkeys by feeding them its embryonated eggs.

THE INTRACAECAL ENVIRONMENT OF HISTOMONAS

In the caecal contents of the chicken or the turkey, we have a medium subject to sudden and extreme changes. Thus on the functional evacuation of the caeca, most of the *Histomonas* present are expelled from the host. In the refilling of the caeca with material from the small intestine, there are doubtless sudden influxes of matter quite unlike that previously present. Extreme variation is also found in the water content of the caecal material which may be of the nature of a foamy fluid or firm and dry in character. *Histomonas* nevertheless maintains itself notwithstanding the vicissitudes encountered in the normal functioning of the caeca and by rapid multiplication makes good the losses which occur through the periodic emptying of these organs. Conditions may arise, however, which may result in the complete eradication of this protozoön. Occasionally following acute

blackhead with complete caecal obstruction, in association with the formation of caecal cores, *Histomonas* disappears from the host, and the carrier state fails to become established. Furthermore great differences are noted in the course of the infection in carriers. While laboratory-reared chicks usually serve as suitable carriers and *Histomonas* is maintained for indefinitely long periods at fairly high and constant levels in their caecal discharges, on occasion similarly reared chickens prove to be more or less unfavorable carriers. If, in the latter case, a number are inoculated on a given occasion, the protozoön becomes established in the caeca of some, while others fail to become infected and some of the infections produced are transient in character. The microscopic study of the caecal discharges may show great variation in the numbers of *Histomonas* not only in individual birds but from day to day in a given individual, while the general average may be low. There is also a marked variation in the appearance of *Histomonas* as it occurs under the varying conditions of the caecal contents. When flourishing, the organism appears in large numbers and shows vigorous movement, but under unfavorable conditions it occurs in small numbers and may appear faint, granular, and with feeble motility. Even when occurring in considerable numbers, the organism may appear less refractive than on other occasions. Great variation in its size is noted in different birds and on different occasions in the same host.

During a period in which the infection in the groups of carriers under observation was being maintained at a low level, even tending to die out in some individuals, it was observed that a large proportion of *Histomonas* present were infected with *Sphaerita*, few of the organisms above medium size being free from this parasite. The question thus arose whether *Sphaerita* was of itself destroying *Histomonas* or whether it was merely an index of other unknown lethal conditions. When under such conditions *Histomonas* was isolated in culture, *Sphaerita* was not carried over, notwithstanding the fact that such cultures were difficult to maintain on account of the starch-destroying activity of the associated bacteria. Thus even under a standardized laboratory regime, the caecal contents of the chicken may vary to such an extent as to be for periods fully favorable for the maintenance of *Histomonas* and at other times more or less unfavorable. Since the cultivation of *Histomonas* in vitro is profoundly influenced by the nature of the associated bacteria, it appears probable that the variation in the flora of the caeca may likewise affect the life of the organism.

MORPHOLOGICAL AND BIOLOGICAL CHARACTERS OF *Histomonas meleagridis*

This protozoön living in a widely varying environment presents great morphological variation. In an earlier paper (1919), there were recorded differences in size, contour and staining reaction between invading forms, those at a later stage of the infection and those eventually isolated by tissue cells in initiation of reparative processes. There are likewise notable differences in appearance of the free-living forms which are more or less correlated with the nature of the material in which they are found, although there may be considerable variation in those taken from a given source. It appears that the refractive property of the individual protozoön is closely correlated with the nature of the food material utilized; those living on bacteria are non-refractive in contrast with those living on starch, which appear bright and have sharp contours. Refractivity is also more or less dependent on the general health of the individual organism and those that are feeble and degenerating invariably appear faint and granular. The following description deals with the appearance of the protozoön in life, after fixation and in stained films.

In the caecal discharges, *Histomonas meleagridis* presents a variety of appearances. When thriving under optimum conditions, it is somewhat refractive, shows both active amoeboid motility and rhythmic rotatory movements so that in the absence of other protozoa it is readily recognized. Large clear refractive forms resembling those found in diseased tissue appear at about the time that invasion of the caecal mucosa is presumably taking place, as indicated by the appearance of leucocytes and red blood corpuscles in the discharges, i. e. in the chicken often from the third to the fifth day of infection. The healthy, active forms occurring in the caecal discharges after the carrier state becomes established appear as rounded bodies exhibiting a jerky, rhythmic oscillatory movement and commonly having a wavy-bordered pseudopodium protruding from some portion of the surface. Motility is less pronounced immediately after the cover-glass preparation of the saline-diluted discharge is made, but becomes well marked in the course of two or three minutes at room temperature. On elevation of temperature, the rhythmic beat becomes correspondingly rapid. Under favorable conditions and with high magnification, the flagellum may be seen stroking in one direction against the surface of the protozoön and causing it to turn, at least at room temperature, not more than one-third or one-fourth

of a full rotation at each stroke. The stroke of the flagellum causes counter clockwise rotation in the great majority of the organisms observed in fresh preparations. In the recovery from each stroke of the flagellum, the body may swing back towards its former position, but some progress in rotation is usually accomplished. The regularity of the rhythm is alone sufficient to distinguish the motility of *Histomonas* from movement imparted to cells by motile bacteria. On one occasion, four active flagella were distinguished projecting from the surface of a living organism.

The study of freshly made preparations shows an increase in amoeboid activity as the organisms come in contact with surfaces. Low, wave-like pseudopodia are extended into finger or arm-like projections with the terminal portions having a frayed-out appearance due to the formation of delicate processes (Fig. 7). As the organisms spread out in contact with surfaces, they appear much larger than in the rounded state. The contour of the organism changes very rapidly even at room temperature so that it is difficult to obtain camera lucida drawings of motile forms or even to sketch them adequately. Hair-like or rod-like processes are often seen projecting from the more rounded forms, and in some instances large areas of the surface are thickly studded with such structures which are constantly being extended and retracted (Fig. 9).

Cytoplasmic inclusions of the nature of coarse bacilli, occasionally starch granules, and more rarely red blood corpuscles are recognizable in the living organisms. The avian red blood corpuscles are not infrequently ingested when hemorrhage is present. In an experimentally infected turkey which had received injections of large doses of "naganol," a German remedy for trypanosomiasis, many *Histomonas* were found distended with red blood corpuscles, and in many not showing these cells, the cytoplasm was distinctly tinged a light mahogany color, perhaps due to the presence of some haemoglobin compound resulting from the digestion of the red cells. The cytoplasm, when for the most part of granular appearance due to the presence of inclusions, often shows a clear portion at one end of the organism and this portion shows the greatest amoeboid activity. The position of the flagellum furnishes the only obvious basis for orientation of structure in this species, pseudopodia being extended from any portion of the surface. That there is, however, some degree of polarity, probably associated with differences in the specific gravity within the body of the organism, is shown by the preponderating frequency of

counterclockwise rotation. In those forms with a granular interior, the cytoplasm may be considered to be differentiated into ectoplasm and endoplasm. Many forms occur, however, which are clear throughout.

Histomonas even when present in large numbers in the caecal discharges is frequently inactive and is approximately spherical. Even such forms are recognizable, for they differ from host cells in being evenly distributed throughout the preparation without clumping, and in their uniformly smooth, spherical shape. Furthermore, in such spherical forms, a portion of the cytoplasm is often clear and devoid of granules. On the other hand, the diagnosis of a given cell in the absence of characteristic motility is often quite impossible even after long acquaintance with *Histomonas* in its various forms.

In culture medium provided with rice starch, *Histomonas* attains a larger average size than in the caecal discharges, although on occasion large organisms may appear in the latter. Culture forms are also in general much more refractive. A large proportion of these contain particles of starch and bacteria in varying quantity. Bone charcoal, mammalian red blood corpuscles and finely comminuted vegetable material are also ingested when added to the medium. If a culture of *Histomonas* is examined at intervals, on some occasions few organisms will be found showing flagellate motility, nearly all being actively amoeboid (Fig. 8), while on other occasions the majority will be more nearly spherical and show rhythmic flagellate motility. If watched for a time, many such forms on contact with surfaces are seen to become actively amoeboid, while still showing actively lashing flagella. Protoplasmic processes vary greatly in character. Some organisms similar to ones noted in the caecal discharge spread out into a thin, actively motile sheet with irregularly scalloped edges (Figs. 9 and 41); some show smooth, wave-like projections, while others send out slender, finger-like processes. Occasionally hair-like processes, or long straight bands are extended. In other instances the processes are more or less bent or even spatulate in character (Fig. 9). Perhaps the most characteristic of pseudopodia are the long ones which fray out into numbers of delicate, tapering processes (Figs. 40, 42 and 43) which might readily be missed with other than an oil immersion lens.

Histomonas in its flagellated phase shows great variation in size from minute forms measuring no more than 4.5 microns (Fig. 24), to large ones measuring 25 microns in diameter (Fig. 10), and flattened

forms often measuring considerably more. There is comparatively much less size-variation in a sample from a caecal discharge than is presented in one from a culture, and on the whole the organisms average rather larger in the latter medium. A preponderance of small forms may appear, in some instances in cultures a few days old, possibly the result of rapid multiplication, in others under conditions of starch starvation when the organisms are dying off. Many of the small forms appear insufficient in size to engulf starch particles and doubtless live for a time on other material.

A large proportion of *Histomonas* propagated in medium supplied with rice starch are intensely iodophilic. They may stain unevenly but the clear, non-granular portion of the cytoplasm is deeply colored. The stained portion appears as a cloud, sometimes of even intensity and in other instances somewhat blotchy. When the preparation is treated with full strength iodine solution (5 per cent potassium iodide in saline solution with iodine added to saturation), the iodophilic material escapes in a large globule, especially from organisms that are extended in amoeboid motion when brought in contact with the iodine. A certain proportion of the organisms are not especially iodophilic and these are invariably devoid of starch. While on occasion forms occurring in caecal material may be iodophilic, usually this peculiarity is lacking, probably due to the paucity of starch. Iodine has also been employed to fix *Histomonas* with pseudopodia extended and for the study of the flagella. The following method has been found useful. First the surface of a clean slide is marked with paraffin to prevent the flattening or crushing of the organisms through the pressure of the cover glass. A small drop of material rich in organisms is placed on the slide and covered with a cover glass. After an interval of several minutes, the organisms will have extended their pseudopodia, a point which should be checked by microscopic examination, when the iodine solution is added in such a way that it will run in from the edge of the cover glass. The protozoa immediately acted upon by the iodine show the outlines of the most delicate protoplasmic processes as in life, while the flagella also stand out very clearly (Figs. 39, 40, 42, 43, 45 and 46).

Other reagents also serve to fix the protozoön in extended form. With formalin fixation, the iodophilic portion of the cytoplasm remains clear, but with Zenker fixation the organism appears granular throughout (Fig. 44). With the addition of osmic acid, organisms immediately acted on tend to burst and discharge their starch granules,

those acted on more gradually show no staining indicative of the presence of lipoid substances.

Histomonas in stained preparations.—The following description is based on the study of films wet-fixed either in Schaudinn's or in Zenker's fixatives, stained by the Heidenhain hematoxylin method, both with and without counterstains, and dry fixed films stained by the Giemsa method. While flattening and distortion of structure occur with the latter method, these features often work to advantage in the study of minute, closely placed structures. Stained preparations serve further to confirm the great variability of *Histomonas* as observed in life. Size differences are accentuated through the greater degree of flattening in the larger organisms. The cytoplasm shows a wide variation in its reaction to the Giemsa stain. For descriptive purposes, three types of organisms may be recognized on the basis of staining qualities of the cytoplasm although all three intergrade one with another. It is found that the character of the cytoplasm is profoundly influenced by the nature of the food utilized. Thus the large, vigorous, more refractive organisms, i. e. the starch-feeding forms that show an abundance of iodophilic material, are not stained satisfactorily by the Giemsa method. The contour of the organism is represented by a thick, smooth line and the cytoplasm within remains unstained and shows little in the way of structure aside from such starch particles as may be present. Such forms show so little in stained preparations that they have not been adequately represented in the figures furnished. In contrast, those forms that are feeding on bacteria rather than starch show a clear, deeply blue-stained cytoplasm in which bacteria or other inclusions may be seen (Figs. 18–21, 29–31). A third type is represented by organisms the cytoplasm of which is in general granular rather than homogeneous and which takes a purplish rather than a clear blue stain (Fig. 28). In these there may be a peripheral clear layer. The significance of such forms is not understood although it is possible that they represent organisms in the cytoplasm of which there is storage of nutritive material.

The cytoplasm may be homogeneous throughout showing no hint of differentiation into ectoplasm and endoplasm, or such differentiation may be quite distinct. The latter condition is especially true of the granular forms last described. The differentiation into ectoplasm and endoplasm in this species appears therefore to be a temporary one, correlated with a phase of physiological activity. Such differences relative to the character of the cytoplasm are readily distin-

guished in living organisms and have already been considered. The nucleus in both the carrier and the culture forms of *Histomonas* is in general relatively small, as already noted in those invading tissue, but is brought out in stained films much more readily than in stained sections. There is no fixed size-ratio relative to the cytoplasmic mass, some organisms of any given size having minute nuclei, others larger ones of relatively coarse structure (Compare Fig. 23 and Fig. 28). Stained preparations indicate a wide variation in the chromatin content. The resting nucleus, as seen in stained films shows granules either fairly evenly distributed or lying against the inner surface of its membrane.

Histomonas may be considered to be normally uniflagellate. Occasional large coarse forms occur with as many as four flagella without indication of division of the single nucleus present (Fig. 28). Biflagellate forms also occur rather frequently (Figs. 31 and 32). The flagellum commonly attains a length slightly greater than the diameter of the organism in its rounded state but is frequently considerably longer, while at other times a large proportion of the organisms may show only short, stubby flagella. The structures near the origin of the flagella vary greatly in appearance in Giemsa preparations. There may be a single, deeply stained granule at the origin of the flagellum from which faint diverging lines extend to the adjacent surface of the nucleus. In some instances, there is a condensation of the cytoplasm around the area traversed by these lines (Fig. 32). In many organisms a second granule is seen internal to the one from which the flagellum arises (Fig. 30). In some instances an ill-defined mass of deeply stained material either obscures or replaces the granules. The flagella in multiflagellate forms arise from such a structure which it has not been possible to resolve into well defined granules, one for each flagellum. It appears quite probable that the granule at the origin of the flagellum is of the nature of a blepharoplast and that the second granule is centriolic in character, but the small size of these structures does not lend itself to assurance of interpretation such as may result from the study of larger and more favorable species.

Multiplication is effected through binary division. Binucleate forms occur in great numbers in some material, but multinucleate forms have not thus far been recognized. Nuclear division is observed in aflagellate forms as well as in others with one, two or four flagella. For purposes of comparison, division forms derived from liver lesions planted in culture medium are figured (Figs. 13-16) together with

one from caecal discharge (Fig. 21) and others from cultures (Figs. 33, 36, 37 and 38). The process is quite similar in organisms from all three sources. In contrast to the wide separation of the daughter nuclei observed at the end of nuclear division in tissue forms, the flagellated forms often show two daughter nuclei lying side by side although in some the two nuclei are widely separated. The spindle or paradesmose of the dividing nucleus is often less conspicuous in the flagellated forms studied in films than in the tissue forms studied in stained sections but otherwise it is of similar appearance in both types. It often appears as a bright, unstained thread of considerable length connecting the division centers (Fig. 36). Distinct chromatin granules, evidently of the nature of chromosomes are seen in the successive stages of nuclear division, but the enumeration of these as well as the determination of other minute features of nuclear division have not been attempted on account of the difficulties and potential inaccuracies involved in interpreting structures so minute. No structures that may be interpreted as parabasal or axostyle have been observed. In fact, cell structures other than those of centriolic or blepharoplastic nature, the associated spindle or paradesmose during division and the nucleus itself, appear to be wholly lacking.

A considerable degree of selectivity in regard to food material is shown by *Histomonas*. In a stained film, some organisms are found that contain only large bacilli, others very minute bacilli, some are loaded with starch particles, and others show no inclusions whatever. A mixture of various types of inclusions is found, however, in a large proportion of individuals. When red blood corpuscles are added to the medium, a certain proportion of the organisms engulf them and in some instances the entire surface of the latter is studded with adherent red cells. Inert material, such as wood charcoal, is taken up in considerable amount.

Histomonas in the caecal worm.—*Histomonas* has been found in the epithelium of the gut of *Heterakis gallinae* from cases of acute blackhead produced by feeding the embryonated eggs of this worm and also from carriers which had similarly been fed worm eggs. This phase of development has not been adequately investigated. The scant material available has shown the protozoön confined to the epithelium of the gut of ten-day and twelve-day old worms developing in chickens, and several were found similarly situated in a twenty-one day old worm from a young turkey. While the protozoön as found in the worm shows a very dense granular cytoplasm (Fig. 47), the nucleus

and blepharoplastic structures are essentially similar to those of *Histomonas* occurring elsewhere. Processes having the appearance of pseudopodia have been observed in fixed material, and a typical division form has been seen. The protozoön in this situation lives upon the coarse globules, presumably lipoid material, stored in the intestinal epithelium of the worm, a diet quite different from that supplied by the culture medium employed or by caecal contents. While *Histomonas* in avian tissue cannot be regarded as an intracellular parasite, its occupancy of the intestinal epithelium of the worm renders it here essentially intracellular. The occurrence of nests of several organisms in the epithelial cells is probably due to multiplication. The mode by which it is transmitted through the worm egg to new avian hosts remains to be worked out.

Attention has already been called to the lack of encysted forms of *Histomonas*, and its failure to survive in lesions after death or in discharges outside the body. It dies off rapidly in cultures left at room temperature, an overnight exposure being sufficient in some cases to destroy the organism. It nevertheless withstands freezing for an hour or more in culture and on rapid thawing will immediately resume movement. However, freezing overnight at low temperatures, -15° C., is sufficient to destroy it. Experimental evidence of its occurrence in *Heterakis* ova has already been presented (Section II). In this situation, it furnishes evidence of great resistance, survives New England winters in the soil, and in this way furnishes a means of transmitting histomoniasis to young birds that have never in any way been associated with older ones.

DISCUSSION

The biological properties of *Histomonas* should be taken into account in consideration of the claims of the transmission of the protozoön through the avian egg to the newly hatched bird. Schlotthauer and Essex (1931) have reported the occurrence of fatal blackhead in turkey poults within the first week of life. Their account and description of the disease in birds over a fortnight old is quite consistent with blackhead but the nature of the cases in which death occurred during the first week of life is not wholly clear. We have long been familiar with a condition in very young chickens and turkey poults which might readily be mistaken for caecal blackhead. The caeca in such cases are completely occluded, with well developed cores but stained sections fail to reveal either *Histomonas* or any pronounced inflamma-

tion of the caecal wall. This condition is responsible for a considerable amount of the early mortality in certain lots of birds and is associated with an abnormality of the fecal discharges causing a caking of the feathers around the anal opening. The etiology of the condition is not understood other than that the number of cases may be increased by chilling. On the basis of long experience with this condition and with mild cases of histomoniasis, we would not undertake to make a diagnosis of the latter, especially in crucial cases, on the basis of gross pathology, even though liver as well as caeca showed disease. The demonstration of a single case of histomoniasis, occurring among properly isolated, incubator-hatched birds would furnish an important indication of maternal transmission through egg to offspring, but no such evidence is available either in the report of the above authors or in the large series of turkeys and chickens reared under controlled conditions in our own investigations. Histomoniasis is readily recognized in laboratory stock, and is, except in rare instances, a persistent infection with a high probability of spontaneous transmission to other birds of the same group. No explanation is offered by the above investigators as to the mechanism of maternal transmission, how the protozoön gets into the egg, where it occurs in the egg or how it gets to the alimentary tract of the chick. Nor do they give due consideration to the acuteness of blackhead infection in very young birds. In the course of our investigations we have observed inflammation of the caeca at seventy-two hours and death from typical blackhead with extensive liver lesions within six days after the inoculation of young chickens. Thus, under unusual conditions, histomoniasis acquired after hatching might cause very early death.

The following observations may offer some elucidation of the question although they should not be considered as conclusive in nature. If hanging drop preparations are made from a suspension of culture rich in *Histomonas*, and kept at 38° C. the protozoön persists in good condition and in undiminished number for at least twenty-four hours. If a preparation is similarly made except that a small amount of fresh egg albumen is added, the protozoa are all killed on incubation overnight, and in similar preparations to which a small amount of fresh yolk is added, the survival time is not much longer. If *Histomonas* is to survive in the avian egg, it would appear that some form more resistant than those occurring in culture is necessary.

The question of the maternal transmission of blackhead through the egg is one of great importance to turkey raisers. The possibility

of such transmission through the agency of some hypothetical resistant form cannot be denied on the basis of negative evidence although no instance or even indication of it has been encountered either in laboratory or practical experience of many years' standing. Its proof would be furnished by the appearance of histomoniasis in carefully isolated laboratory-reared birds, but in no instance to date has infection occurred under such conditions. Hence the evidence for maternal transmission offered by Schlotthauer and Essex is by no means convincing.

The study of *Histomonas* as it occurs in the avian carrier and in culture has revealed no encysted or resistant form to account for its persistence in soil. Since blackhead may be regularly produced by the routine procedure of feeding the eggs of *Heterakis gallinae* that have been kept in 1.5 per cent nitric acid until embryonated, and also since blackhead may be produced by the feeding of soil, containing *Heterakis* eggs, that has been exposed to the freezing and thawing of the winter months, the conclusion has been reached that a resistant stage capable of transmitting infection to susceptible birds is carried by the worm egg. The experimental evidence is consistent with practical experience in that growing turkeys will acquire blackhead from contaminated soil without any direct exposure to poultry or older turkeys.

The question may be raised as to whether the forms of *Histomonas* here described, some possessing a single flagellum and others multiple flagella, represent two rather than a single species. That the forms in question agree in all characteristics other than in the number of flagella renders this possibility rather improbable. In a protozoön showing such a wide range of variability, occasional precocious multiplication of the flagella previous to nuclear division is not remarkable. Organisms are observed in the process of nuclear division with one, two or four flagella, others with none. Multiflagellate forms are not only encountered in caecal discharges and in freshly isolated cultures, but also in cultures that have been maintained for long periods, one for more than three years. The flagella in both multiflagellate and uniflagellate forms, are similar in appearance and mode of functioning, although often shorter in proportion to the diameter of the organism in the multiflagellate form.

The different morphological types of *Histomonas* previously described in avian tissues and their correlation with stages of blackhead infection are supplemented in the present study by types found in

various other environments. The starch-ingesting forms of *Histomonas*, from the great size attained, their unsatisfactory reaction to stains, and the readiness with which they undergo dissolution with certain reagents, would appear to correspond to those in the "vegetative stage" previously described in blackhead lesions. Probably much of the difficulty in recognition of histomoniasis in stained section is based on the nondescript appearance of such forms. Without perfect fixation they appear as scarcely more than spaces in the tissue and the small nucleus is often inconspicuous, even on deep staining. The smaller, dense, rounded forms are much more readily recognized. Quite as great a variation in the morphology of the protozoön has been found in its study in culture and in the discharges of carriers as was previously observed in infected tissues.

Difference in type is perhaps based not wholly on environment, for a considerable degree of selectivity with respect to the ingestion of food material is shown in the organisms of a single culture. The ability of the species to adapt itself to sudden changes and to different environments has already been pointed out. Thus, in culture it thrives upon starch, in the bird's caeca it lives largely upon bacteria, during disease it may live on cell fragments and tissue fluid, and in the gut of the caecal worm it is found ingesting the lipoid globules of the intestinal epithelium. The diet of the protozoön appears to affect the general appearance of its cytoplasm whether in life or in stained preparations.

Although the etiological significance of *Histomonas* to the specific disease known as "blackhead" has not been seriously questioned since its discovery by Smith in 1895, nevertheless from discussion that has occurred at live-stock conferences, it would appear that there are those who not are fully convinced. To the author the question involves scarcely more than a definition of blackhead as a reaction of the host to the invasion of its tissues by *Histomonas*. The constant association of *Histomonas* with the lesions of this disease in whatever organ they may occur, the reaction of the host tissues to the protozoön constituting the disease process, the correlation of repair with the elimination of the protozoön, and the experimental production of typical disease by the inoculation of material containing no organism thus far demonstrable other than *Histomonas*, appear to constitute convincing evidence of the etiological significance of this protozoön. Thus we regard histomoniasis and blackhead as synonymous terms and believe that the use of the latter name except for the specific disease in question will result only in confusion.

No evidence is available of the presence of a virus other than *Histomonas* or of any other factor peculiar to the disease. In the next following section it will be shown that the subjection of a culture of *Histomonas* to sufficiently low temperatures to destroy the protozoön renders it noninfective although the associated bacteria survive such treatment. Whether or not it is possible to satisfy the requirements of Koch's postulates, or whether the organism in question has been successfully propagated in vitro, the multiplication of any protozoön within the tissues of a higher animal may not be disregarded with impunity in the consideration of disease, especially when the reaction to the protozoön appears to constitute the disease. By employing diseased tissues, caecal discharges, cultures, or embryonated eggs of the caecal worm which contain *Histomonas*, blackhead is produced as a matter of laboratory routine, quite as readily as any of the well known bacterial infections. It is true that in experimental work on blackhead it is important to employ clean, laboratory-reared stock in order to avoid the possibility of encountering adventitious infection, or immunity resulting from previous infection, and also to avoid the difficulties of diagnosis resulting from the presence of swarms of other species of protozoa in the caecal contents. A rabbit or a guinea pig from almost any source providing it is in good health, may meet the requirements of the bacteriologist, but the employment of birds, not laboratory-reared, will for most purposes yield wholly unreliable data in the investigation of blackhead. It is believed that much of the difficulty involved in the experimental work on this subject lies in the failure to recognize this principle and perhaps also in a lack of ability to identify *Histomonas* on the basis of its morphology. In the latter case the investigator works largely in the dark with reference to the presence of the infective agent in any material that he may employ, and also in the interpretation of his results.

In regard to the systematic position of *Histomonas*, it is included by Wenyon in the family MONADIDAE Kent, 1880, who calls attention to its resemblance to a member of the genus *Oikomonas*. While the process of nuclear division of *Histomonas* is in many respects similar to that described in various species of *Trichomonas*, it shows, apart from nucleus and flagellum, none of the structural differentiation of the better known intestinal flagellates and is moreover actively amoeboid. Thus it appears preferable not to undertake anything further in the way of classification until other more or less related species are more carefully studied.

SUMMARY

Routine methods of producing histomoniasis or blackhead that will furnish sources of material for the study of *Histomonas meleagridis* are reviewed.

A method for the isolation of *Histomonas* from the caecal discharges of carriers and for its continuous propagation on artificial medium in association with bacteria is described.

The lack of satisfactory evidence of maternal transmission of blackhead infection through egg to offspring is pointed out.

The morphology of *Histomonas meleagridis* as it occurs in the caecal discharges is similar to that of the forms that develop in culture, although a somewhat greater average size is attained in the latter. The species may be considered as normally unflagellate, but there occur multiflagellate forms of large size which may show as many as four flagella. The cytoplasm may be homogeneous, staining a clear blue by the Giemsa method, or it may remain practically unstained in starch-ingesting individuals. There are also forms that show a purplish staining, granular cytoplasm and some of these present a clear ectoplasmic layer. Starch-ingesting organisms are intensely iodophilic, the iodine staining material being concentrated in a portion of the cytoplasm devoid of granules. In the caecal contents, in the presence of hemorrhage, avian red blood corpuscles are frequently ingested and various materials in addition to starch and bacteria are ingested in culture.

The forms here described from caecal discharges and cultures correspond closely with respect to the appearance of the centrioblepharoplastic structures, the nucleus, and the process of nuclear division, with those previously described in diseased tissues. Perhaps the most striking feature of *Histomonas* is its oscillating movement in which there is partial rotation on the stroke of the flagellum with a tendency to swing back as the latter recovers. The flagellated forms quickly take on amoeboid activity in cover glass preparations, becoming extended especially when in contact with surfaces and at the same time may retain their flagella over a long period. There is great variety in appearance presented in the amoeboid activities of the organism which may show sluggish changes of shape or rapidly extended pseudopodia which may be wave-like, finger-like, in the form of slender bands, rods or hair-like processes, but those that are frayed into fine, tapering, hair-like projections are probably more typical of the species. On occasion, the organism may flatten itself

out into a thin motile sheet of irregular outline. In the intestinal epithelium of *Heterakis*, *Histomonas* is found to ingest the lipoid globules of the invaded cells and presents a dense granular-appearing cytoplasm.

No encysted form of *Histomonas* has been discovered thus far, and, although there is experimental evidence indicating the presence of a resistant stage in the *Heterakis* egg, it has not been microscopically demonstrated in the latter.

PLATE III.

In figures 6 to 9, *Histomonas* is represented as in life at 1020 diameters.

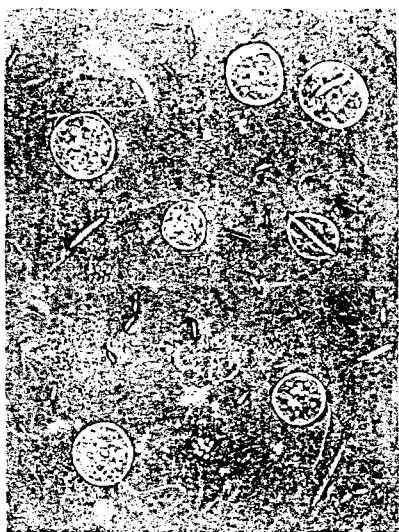
FIG. 6. *Histomonas* from a freshly passed caecal discharge of a chicken carrier. Such forms show a jerky rotatory movement, are more or less rounded and are commonly not refractive.

FIG. 7. *Histomonas* from the same material as above but after an interval of five minutes after the preparation was made. The organisms have commenced active amoeboid movement and are spreading out with ragged-edged, sheet-like pseudopodia.

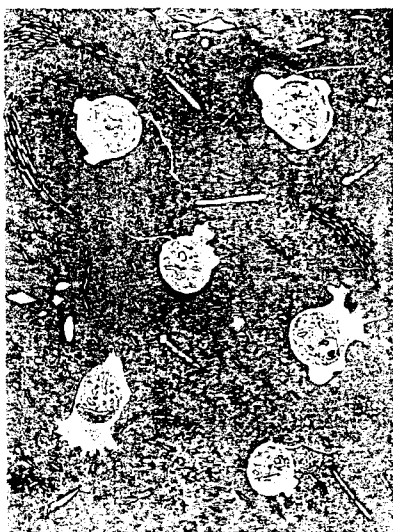
FIG. 8. Amoeboid aflagellate forms of *Histomonas* from a vigorous six-day culture.

FIG. 9. Selected extreme types from *Histomonas* cultures. The two lower drawings at the left depict the change in outline of a single organism within an interval of about a minute and a half at room temperature. Below and to the right an organism is shown with surface studded with slender rod-like processes, probably not normal although actively motile. The uppermost organism represented has ingested four mammalian red blood corpuscles from those supplied in culture, somewhat below this is a non-motile clear hyaline sphere, and to the right is a small actively motile hyaline form spread out in a thin sheet.

PLATE III



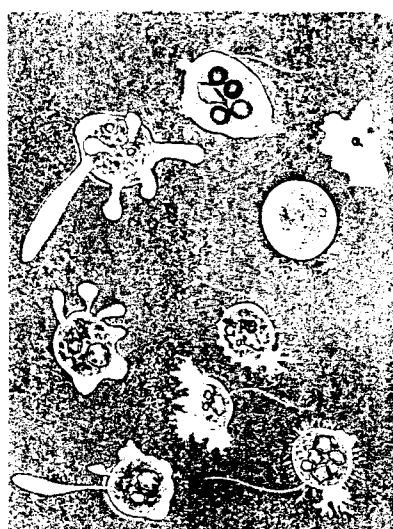
6



7



8



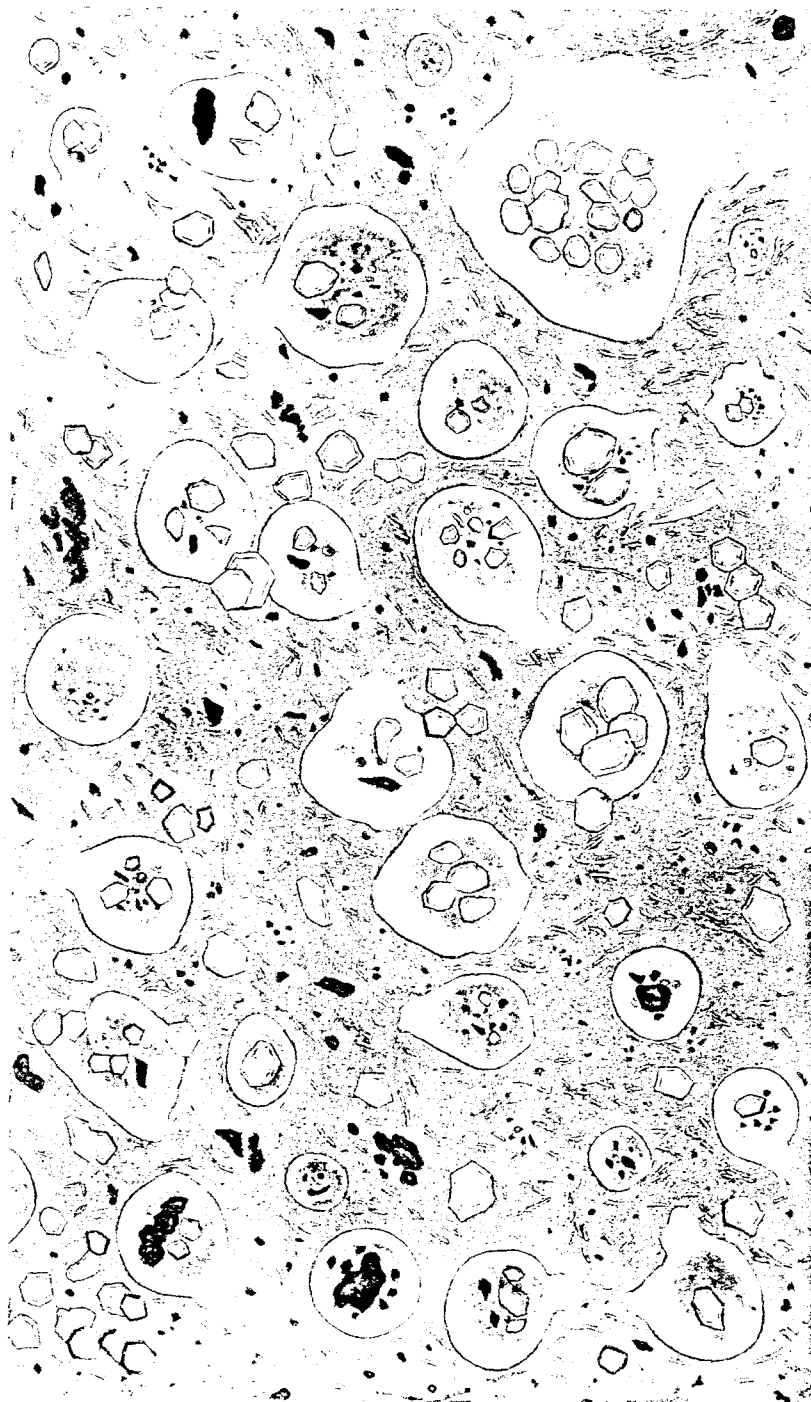
9

Histomonas in caecal discharge (above); various forms seen in culture (below). X 1020.

PLATE IV.

FIG. 10. Sediment from a rich culture of *Histomonas* magnified to 1300 diameters. The bright angular bodies both free and within the organisms represent starch particles, the black material "bone black." There are bacilli scattered throughout the field. The flagellum even when present is not always readily distinguished. Such starch feeding forms are in general larger and much more refractive than those usually encountered in the caecal discharges of carriers (Compare with Figs. 6 and 7). The characteristic pseudopodia fraying out into ragged endings are apparent in several of the organisms. In the upper right hand corner are selected large and small forms indicating the extremes in size variation.

PLATE IV



10

Histomonas meleagridis in fresh preparation from culture. X 1300.

PLATE V.

Figures 11 to 21 inclusive are from a thirty-eight day old turkey from the first well controlled experiment in which blackhead infection was produced by feeding *Heterakis* ova previously treated with 1.5 per cent nitric acid. Death, October 14, 1921, from blackhead at the end of four weeks from the feeding of *Heterakis* ova. Giemsa stained films. Figures 11 to 17 were from liver-lesion material that had been in culture medium from two to twelve hours; figures 18 to 21 from caecal material in culture medium from five to twelve hours. Figures 25 to 28 are drawn from stained films of caecal discharges of a chicken carrier experimentally infected thirty-five days previously. All other figures are from a Giemsa stained film of a *Histomonas* culture. All figures reproduced at 1150 diameters.

FIG. 11. Large, lightly stained *Histomonas* showing an intracytoplasmic filament extending from blepharoplast,—from liver lesion twelve hours in culture medium.

FIG. 12. Deeply stained granular organism showing a similar filament,—liver lesion twenty-four hours in culture.

FIG. 13. Division form, the daughter nuclei widely separated on paradesmose,—same preparation as Fig. 12.

FIGS. 14 and 15. Large forms in process of nuclear division, possibly some disarrangement of structure through pressure in preparation of film,—same preparation as Fig. 12.

FIG. 16. Binucleate organism with double extranuclear granules clearly shown,—same preparation as Fig. 12.

FIG. 17. *Histomonas* showing a short flagellum as well as an internal filament,—from liver lesion two hours in culture medium.

FIG. 18. *Histomonas* with short flagellum, derived from caecal material that had been twelve hours in culture medium. The cytoplasm shows ingested bacteria.

FIGS. 19 and 20. Similar forms from caecal material five hours in culture medium.

FIG. 21. Division form showing two flagella derived from caecal material five hours in culture medium.

FIG. 22. Starch laden *Histomonas*, no flagellum visible. Culture, Giemsa.

FIG. 23. Form illustrating small size of nucleus in many organisms, cytoplasm homogeneous and intensely basophilic. Culture, Giemsa.

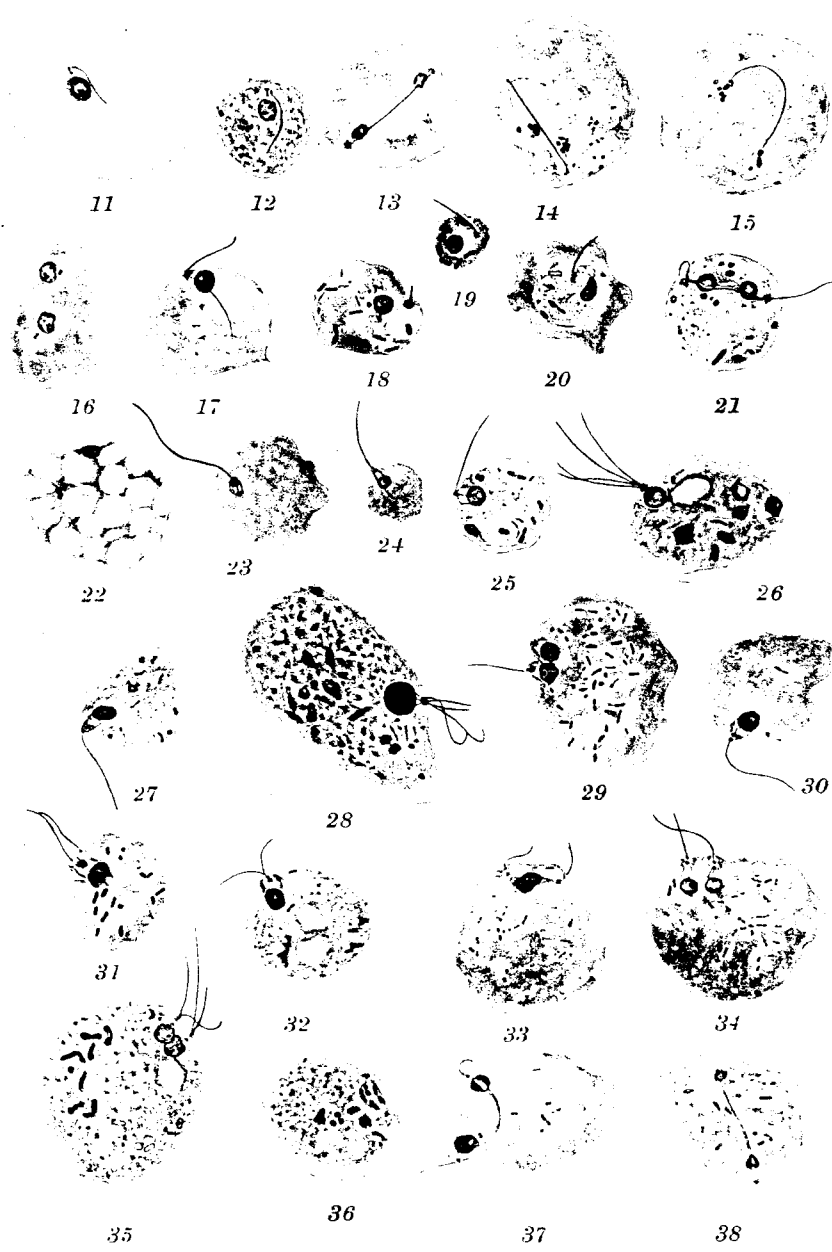
FIG. 24. Minute flagellated *Histomonas*, cytoplasm basophilic. Culture, Giemsa.

FIG. 25. Uniflagellate form with ingested bacteria. Caecal discharge, Heidenhain's haematoxylin.

FIG. 26. Uninucleate, quadriflagellate *Histomonas* with starch grains and several bacteria. Caecal discharge, Heidenhain's haematoxylin.

FIG. 27. Uniflagellate form. Caecal discharge, Giemsa.

PLATE V



Histomonas from stained films. X 1150.

FIG. 28. Giant, quadriflagellate form with large nucleus. The flagella arise from a single blepharoplastic mass. Cytoplasm differentiated, with clear ectoplasm, and a coarsely granular endoplasm containing bits of material, possibly starch. Caecal discharge, Heidenhain's haematoxylin.

FIG. 29. Binucleate form with a single flagellum visible. Culture, Giemsa.

FIG. 30. Uniflagellate form, two granules near origin of flagellum.

FIG. 31. Biflagellate, uninucleate form. There is a granule at the base of each flagellum, and a single coarser mass below.

FIG. 32. Biflagellate, uninucleate *Histomonas*, with a zone of dense cytoplasm surrounding blepharoplastic area.

FIG. 33. Division form, a short flagellum arising from each blepharoplast.

FIG. 34. Biflagellate, binucleate organism with blepharoplastic granules distinct from centrioles.

FIG. 35. Quadriflagellate, binucleate form. Nuclei in close apposition.

FIG. 36. Aflagellate culture form in early division. Chromosomes and paradesmose visible.

FIG. 37. Division form with two short flagella, nuclei widely separated on paradesmose.

FIG. 38. Division form showing no flagella.

PLATE VI.

The organisms are represented in this plate at 1150 diameters.

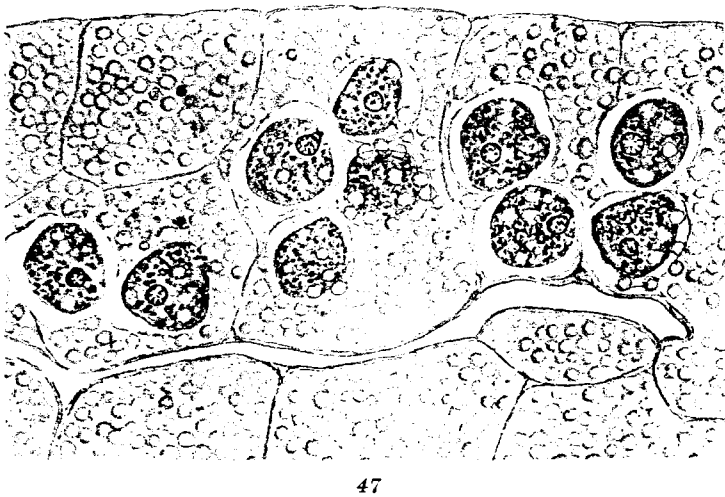
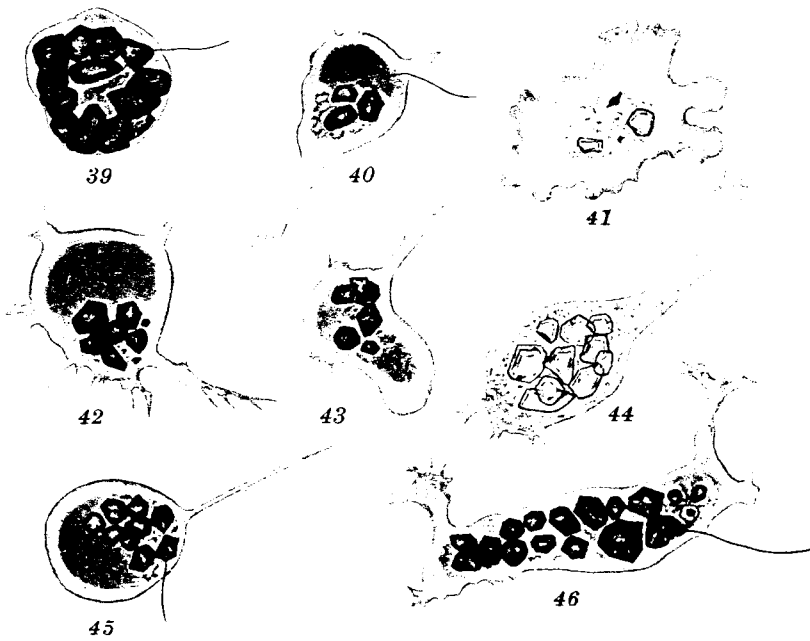
FIGS. 39, 40, 42, 43, 45 and 46. *Histomonas* from culture, killed and stained with strong iodine solution after being allowed time in cover glass preparations to become actively amoeboid. The included starch grains are stained intensely by the iodine and the diffuse cloud of iodophilic material is represented by deep shading. The organism shown in the first figure has remained rounded. The slender hair-like and coarser arm-like processes apparent in the others are fixed as seen during life. (On account of the continuous rapid change of shape, accurate camera-lucida drawings of such forms are not obtainable in life.) The flagellum is apparent in four of the figures.

FIG. 41. Represents *Histomonas* assuming the form of a thin, clear sheet with irregular contour; sketched as accurately as possible from a living organism.

FIG. 44. *Histomonas* in extended form after Zenker fixation which caused the cytoplasm to appear granular throughout.

FIG. 47. *Histomonas* in the epithelium of the gut of an eleven-day old *Heterakis gallinae*. (The chicken from which material was derived showed acute blackhead, i. e., caecal involvement and liver lesions, the result of the experimental feeding of large numbers of *Heterakis* ova eleven days previously.) The protozoön developing in the intestinal epithelium of the worm has a dense granular cytoplasm, and apparently ingests the lipoid globules of the invaded cells. The blepharoplast is apparent in several of the organisms shown.

PLATE VI



Histomonas, fixed with pseudopodia extended (above); and in intestinal epithelium of caecal worm (below). X 1150.

IV. LOSS OF VIRULENCE IN *HISTOMONAS MELEAGRIDIS* IN CULTURE AND THE IMMUNIZING PROPERTIES OF AN ATTENUATED STRAIN.

While *Histomonas meleagridis* has shown no appreciable modification in regard to its morphological characters in the course of long propagation in culture medium, biological changes as, for example, loss of virulence have become apparent. The records of experiments demonstrating such loss of virulence as well as the immunizing properties of an attenuated strain of this protozoön will be presented. In the development of *Histomonas* in its avian hosts, the protozoön may be found multiplying in the tissues, in which case it is associated with a disease process, or it may maintain itself indefinitely by multiplication in the caecal contents of apparently normal birds. Thus in the chicken, the disease blackhead, caused by the invasion of the tissues by *Histomonas*, is generally mild in character and of brief duration. The protozoön is eliminated from the tissues on recovery from the disease but usually continues to multiply in the caecal contents, thereby establishing the carrier state. Moreover, it is not improbable that in carriers the protozoön may from time to time invade the tissues to a slight extent, otherwise it is difficult to see how immunity is maintained. Thus we often have no means of ascertaining with certainty during life whether for any given period the protozoön is wholly excluded from the tissues or is now and again concerned in slight, transient invasions of the latter. In view of this uncertainty in regard to the exact distribution of the protozoön in carriers and also for the lack of another appropriate term, it is found convenient to refer to a case in which *Histomonas* has established itself, even though it may be confined to the caecal contents, as one of "infection." The term "superinfection" will also be employed in a similar sense implying the establishment of secondary strains of *Histomonas* in the caeca, irrespective of whether or not they invade the tissues.

Since the rectal injection of infective material has proved the most reliable and convenient method of producing a form of blackhead which agrees essentially with natural infections, it has been adopted as a routine procedure throughout the present investigation.

STRAINS OF HISTOMONAS AND THE REACTIONS OF INOCULATED CHICKENS AND TURKEYS.

The history of the first strain of *Histomonas* to become attenuated and which will be designated as Strain A, is briefly as follows:

On January 8, 1930, a laboratory-reared turkey was experimentally infected by furnishing it with food contaminated with henyard soil in which were large numbers of embryonated *Heterakis* eggs. This turkey developed blackhead and its liver lesions were ground in saline and the resulting suspension was rectally injected into a group of chickens. The infection that followed was transferred three days later to another group of chickens and from one of these *Histomonas* was isolated with associated bacteria in culture February 6, 1930. The isolation was made on the Locke-egg-serum medium of Boeck and Drbohlav (1925), but following the first few transfers on this medium, it has been propagated on the agar, saline, serum, starch medium described in a previous section. This strain being maintained in culture by weekly transplants was next employed to inoculate chickens on December 12 and 19, 1930, and on January 9, 1931. On each of these occasions all the inoculated birds showed extensive caecal disease and in some characteristic liver lesions also resulted from the inoculation. This strain of *Histomonas* had thus maintained its pathogenicity for a period of eleven months' growth in the culture tube. No further inoculations were made with Strain A until January 5, 1932, or twenty-three months after its isolation, when it was found to be almost completely innocuous for chickens. The inoculation of this attenuated strain serves to establish the carrier state at once, for it is possible to demonstrate *Histomonas* in the caecal discharges at almost any time following inoculation.

Substrain A 1 was isolated on June 21, 1932 from a chicken inoculated on March 19 of the same year with a culture of Strain A. Cultures of this Substrain have proved uniformly long lived and rich in *Histomonas*, but non-pathogenic.

The immunizing properties of an attenuated strain.—Since another newly isolated culture of *Histomonas*, Strain B, has been proved pathogenic for chickens, the protective properties of Strain A were next tested. Strain B was isolated in culture on February 27, 1932, from a fifty-eight day old laboratory-reared chicken that had been fed embryonated *Heterakis* eggs seven days previously. The results of the immunity-tests and control inoculations are presented in Table VII.

Stained sections of the minute opacities observed in the caecal wall in several of the vaccinated birds tested with Strain B showed foci in the mucosa infiltrated with *Histomonas*. Such minute lesions have been also occasionally encountered in infections from the Strain A culture and furthermore stained sections have revealed microscopic

TABLE VII.
THE PROTECTIVE EFFECT OF INFECTION WITH AN ATTENUATED STRAIN OF HISTOMONAS.

CHICK*	VACCINATION	TEST-INOCULATION	KILLED	POST MORTEM FINDINGS
8540	Jan. 20, 23, 28 and Feb. 6, rectally injected with Strain A cultures.	Mar. 5, rectally injected with Strain B cultures.	Mar. 11	Two minute opacities in caecal mucosa.
8541			Mar. 12	One minute opacity in caecal mucosa.
8542			Mar. 10	Normal
8543			Mar. 14	1.5 cm. opacity in caecal mucosa.
8544			Mar. 15	One minute opacity in caecal mucosa.
8545	None	Mar. 5, rectally injected with Strain B cultures.	Mar. 10	Caeca extensively diseased.
8546			Mar. 11	Caeca extensively diseased.
8547			Mar. 12	Caeca extensively diseased.
8548			Mar. 14	Caeca extensively diseased.
8549			Mar. 15	Caeca extensively diseased.
8550	None	Mar. 5, rectally injected with Strain A cultures.	Mar. 10	Normal, Histomonas present.
8551			Mar. 11	Normal, Histomonas present.
8552			Mar. 12	Normal, Histomonas present.
8553			Mar. 14	Normal, Histomonas not present.
8554			Mar. 15	Normal, Histomonas present.
8555	Mar. 5, rectally injected with Strain A cultures.	Mar. 15, rectally injected with Strain B cultures.	Mar. 21	Normal

* All chicks were Rhode Island Reds hatched on December 24 except 8555 hatched on January 26.

foci of infiltration with *Histomonas* in cases in which there was nothing abnormal to the naked eye in the appearance of the caecal mucosa. It is apparent from the experiment presented in Table VII that infection with the attenuated strain confers a high degree of protection against inoculations with a virulent strain of *Histomonas*.

That "superinfection" occurs as a result of the test-inoculation of immunized birds with virulent cultures is demonstrated by the pathogenicity of *Histomonas* derived from their caecal discharges. Thus after testing the immunity of Strain A carrier chickens by the rectal injection of the pathogenic Strain B *Histomonas*, the caecal discharges of six of these birds were collected five, seven, seven, eight, nine and ten days respectively after the test-inoculation and injected rectally into eight normal young chickens. These when killed after intervals of from six to eight days showed generalized caecal disease in six, focal inflammation in one, and no gross lesions at six days in the eighth bird, which, however, showed *Histomonas* in the caecal contents. Disease thus resulted from the inoculation of each of the six samples of caecal discharges obtained at intervals up to ten days after the inoculation of Strain A carriers with virulent Strain B *Histomonas*.

Successive passages of an attenuated strain through young birds.—During the course of these experiments, attempts were made to restore the virulence of the attenuated Strain A by rapid passages through both chickens and turkeys, but without success. Thus passage through five lots of chickens inoculated in succession and later on through five successively inoculated young turkeys during a period of seven and a half weeks has failed to produce disease. Neither has this strain become pathogenic through a sojourn of several months in a chicken carrier. On account of its constancy with reference to its non-pathogenicity, the attenuated strain to some extent resembles a "*virus fixé*."

Possible effects of associated organisms on virulence.—The question of whether the difference in respect to pathogenicity now apparent in the two strains is based on the character of the organisms associated with *Histomonas* in the culture tube, has been considered. With the view of separating the associated organisms from *Histomonas* in the virulent culture, the protozoön was killed by freezing cultures overnight at -15° C. The effects of the inoculations of chickens either with the bacterial content of virulent Strain B cultures alone, or in mixture with the attenuated Strain A cultures were next determined. The essential data are furnished in Table VIII. As shown by the results here tabulated, the bacterial content of Strain B culture does

TABLE VIII.
THE EFFECT OF ORGANISMS ASSOCIATED WITH HISTOMONAS IN CULTURE ON PATHOGENICITY.

CHICK*	INOCULATION	HISTOMONAS	DATE KILLED	POST MORTEM FINDINGS
8632	May 17, rectally injected with Strain A cultures of Histomonas.	Present	May 23	Normal
8633		"	May 24	Normal
8634		"	May 25	Normal
8635		"	May 26	Minute opacity in caecal mucosa.
8636		"	May 27	Normal
8637		"	May 28	Minute opacities in caecal mucosa.
8638	May 17, rectally injected with a mixture of Strain A cultures and frozen Strain B cultures.	Present	May 23	Normal
8639		"	May 24	Normal
8640		"	May 25	Normal
8641		"	May 26	Normal
8642		"	May 27	Normal
8643	May 17, rectally injected with frozen Strain B cultures.	Absent	May 23	Normal
8644		"	May 24	Normal
8645		"	May 25	Normal
8646		"	May 26	Normal
8647		"	May 27	Normal
8648	May 17, rectally injected with Strain B cultures.	Present	May 25	Liver and caeca extensively diseased.
8649		"	May 23	Liver and caeca extensively diseased.
8650		"	May 26	Liver and caeca extensively diseased.
8651		"	May 27	Small spots in liver, caeca extensively diseased.
8652		"	May 24	Liver and caeca extensively diseased.
8653	May 17, rectally injected with a mixture of Strain A and Strain B cultures	Present	May 25	Caeca extensively diseased.
8654		"	May 27	Liver and caeca extensively diseased.
8655		"	May 23	Liver and caeca extensively diseased.
8656		"	May 23	Liver and caeca extensively diseased.
8657		"	May 26	Caeca extensively diseased.

* All chicks were Rhode Island Reds hatched on May 10.

not appear to be a significant factor in the pathogenicity of this strain. Results identical with those here presented had been previously obtained in another similar experiment in which *Histomonas* was eliminated from Strain B cultures by freezing the latter for brief periods with longer intervals at room temperature. In that experiment, a series of twenty chicks were employed, being divided into four groups of five each and inoculated respectively with Strain B, Strain A, a mixture of Strain A and frozen Strain B, and with frozen Strain B.

Vaccination of young turkeys.—Having found that infection with the attenuated Strain A *Histomonas* serves to protect chickens against blackhead, protective inoculations were then attempted in young turkeys. Incubator-hatched turkey poults of four different lots were vaccinated at an early age by the rectal inoculation of a mixture of Strain A and Substrain A 1 *Histomonas*.

These lots, designated numerically, were as follows: Lot I was comprised of twenty poults, eight hatched on May 3 and twelve on May 8; Lot II, twenty-seven poults hatched June 5; Lot III, thirty-three poults hatched June 30; and Lot IV, nine hatched August 3, 1932. Lots I and III were obtained directly from the incubator. Lot II consisted of birds from a poor hatch following a great elevation of incubator-temperature toward the end of incubation, and these birds were also exposed to brooder house conditions for two days after removal from the incubator. Lot IV had been in the brooder house for twenty-four hours after removal from the incubator, before being taken to the laboratory.

Not included in Lot III were two poults of the same hatch that died at the age of seven days, one of which showed caecal cores but no evidence of blackhead in study of stained sections, and another killed by accident at the age of fifteen days. Not included in Lot IV were three poults which died in the first week of life, two showing the non-specific typhlitis with caecal cores described in Section II.

Sixteen turkeys of Lot I were vaccinated with Strain A *Histomonas* cultures and from seventeen to nineteen days later were inoculated with Strain B cultures as an immunity-test. Following the test-inoculation, one of these succumbed to caecal histomoniasis while all four similarly inoculated control turkeys died with extensive liver and caecal involvement (see Table IX).

The vaccinated turkeys of Lot II were not given immunity-test inoculations until three months after vaccination, but were in the meantime exposed to contaminated soil. Seventeen turkeys of this lot developed caecal induration in the first two or three weeks of life, this condition appearing before inoculation in six of a group of nine. One that died five days after inoculation showed caecal cores but no

evidence of blackhead, and seven others that either died or were killed showed slight invasion of the tissues by *Histomonas*, in two there were also several minute spots in the liver, but in none of these infected birds was the infiltration with *Histomonas* extensive. In two, death was obviously due to intercurrent infection, there being pericarditis in one and peritonitis in another. The demonstration of two cases of histomoniasis in two uninoculated poults further complicates the results obtained in this experiment, and might be regarded as evidence of maternal transmission of infection through the egg. This conclusion is not, however, justified, on account of a period of exposure of all of the birds of Lot II to brooder house conditions.

Lot II has thus furnished results of little value apart from the fact that it furnishes a group of turkeys exposed early in life to a non-virulent *Histomonas* infection. The immediate effects of the vaccination cannot be judged on account of the intercurrent conditions, i. e. nonspecific typhlitis and bacterial infections. Data pertaining to this lot are summarized in Table X.

In Lot III, twenty-nine poults were vaccinated and four of these when subjected several weeks later to immunity-test inoculations,—two being fed *Heterakis* ova and two being injected with virulent culture,—were shown to be adequately protected while the four similarly inoculated control turkeys succumbed to typical blackhead (see Table IX). The vaccination of the twenty-nine poults was followed by three deaths and in each of these cases there was invasion of the caecal mucosa by *Histomonas*, clearly accounting for the death in one, but in the other two which showed visceral anomalies (see Table X), the slight degree of histomoniasis probably had little if any effect on the health of the bird.

The vaccination of seven poults of Lot IV resulted in the protection of all seven to subsequent inoculations of virulent culture (see Table IX). One of the two controls inoculated with the latter, died of typical blackhead, the other passed through a long period of illness and recovered, but was of no commercial value. When killed two months later, the liver was extensively scarred and lobulated throughout. This turkey was the only one that survived in a total of ten controls that received test-inoculations with virulent *Histomonas*.

All four lots of turkeys were exposed subsequent to their vaccination to farm conditions which had in previous years never failed to produce blackhead. Since several cases of clinical blackhead eventually appeared in the second (June 5th) lot, the birds of this and the third (June 30th) lot were given a test-inoculation with virulent cultures late in the season, that is on October first and October eleventh.

Although there had been two fatal and three non-fatal cases of blackhead in the second (June 5th) lot of vaccinated turkeys, the late test-inoculation furnished no additional cases. In the third

TABLE IX.
BLACKHEAD VACCINATION AND IMMUNITY TEST-INOCULATIONS IN TURKEYS.

TURKEY	HATCHED	VACCINATION	RESULT	TEST-INOCULATIONS	RESULT
8628	May 3	May 10	No symptoms	May 27, June 4 & 6	No symptoms. Killed July 31, caecum scarred.
8629	"	May 16	No symptoms	June 4 & 6	No symptoms
8630	"	"	No symptoms	" "	No symptoms
8631	"	"	No symptoms	" "	No symptoms
8658	"	May 20	No symptoms	June 6 & 8	No symptoms
8659	"	May 20 & 24	No symptoms	" "	No symptoms
8660	"	May 20	No symptoms	" "	No symptoms
8661	"	"	No symptoms	" "	No symptoms
8662	May 8	"	No symptoms	" "	Caecal induration June 18. Recovered.
8663	"	"	No symptoms	" "	Died June 23. Caecal blackhead.
8664	"	"	No symptoms	" "	No symptoms
8665	"	"	No symptoms	" "	No symptoms
8666	"	"	No symptoms	" "	No symptoms
8667	"	"	No symptoms	" "	No symptoms
8668	"	"	No symptoms	" "	No symptoms
8669	"	"	No symptoms	" "	No symptoms. Killed June 20, caeca normal.
8670	May 8	None (Control)	.....	June 4 & 6	Died June 16. Typical blackhead.
8671	"	"	.....	June 6 & 8	Died June 15. Typical blackhead.
8672	"	"	.....	" "	Died June 17. Typical blackhead.
8673	"	"	.....	May 27 & June 4	Died June 7. Typical blackhead.

Lot 1

TABLE IX—(Continued).
BLACKHEAD VACCINATION AND IMMUNITY TEST-INOCULATIONS IN TURKEYS.

TURKEY	HATCHED	VACCINATION	RESULT	TEST-INOCULATIONS	RESULT
8705	June 30	July 2 & 15	Caecal induration	August 2	No symptoms. Killed August 30, normal.
8721	" "	July 6, 14 & 15	No symptoms	July 27 & 29	No symptoms
8702	" "	July 2	No symptoms	July 27*	No symptoms
8704	" "	" "	No symptoms	July 27*	No symptoms
8748	June 30	None (Control)	.....	July 27*	Dead August 11. Typical blackhead.
8749	" "	" "	.....	July 27*	Dead August 15. Typical blackhead.
8750	" "	" "	.....	July 27 & 29	Dead August 8. Typical blackhead.
8751	" "	" "	.....	July 27	Dead August 5. Typical blackhead.
8765	Aug. 3	August 6	Caecal induration	October 1 & 11	No symptoms
8766	" "	August 15 & 17	No symptoms	" "	No symptoms
8770	" "	August 20	Caecal induration	" "	No symptoms
8771	" "	Sept. 2	No symptoms	" "	No symptoms
8772	" "	" "	No symptoms	" "	Slight induration Oct. 11. Recovered.
8773	" "	Sept. 12	No symptoms	" "	No symptoms
8774	" "	Sept. 27	No symptoms	Oct. 11	No symptoms
8775	Aug. 3	None (Control)	.....	Oct. 1	Symptoms Oct. 11. Recovered. Killed Dec. 2. Liver scarred.
8776	" "	" "	.....	" "	Died Oct. 16. Typical blackhead.

* Fed embryonated *Heterakis* ova.

TABLE X.
VACCINATION FOLLOWED BY EXPOSURE TO CONTAMINATED SOIL AND LATE TEST-INOCULATIONS.

VACCINATED TURKEYS	POST-VACCINAL DISEASE	IMMUNITY TESTS	RESULT
Lot II* Twenty-seven poults hatched June 5. June 8, eighteen were rectally injected with sediment of cultures of Strain A. Two of these and three of the other nine turkeys having shown no caecal induration were vaccinated by rectal injection on June 30.	June 13, one died showing caecal cores but no Histomonas in the tissues. Seventeen, including six of the nine uninoculated poults, developed induration of the caeca. Two that died and five that were killed during June showed invasion of the caecal mucosa by Histomonas. Several small liver lesions were found in one of the uninoculated poults.	June 30, the nineteen survivors were placed on contaminated soil. Oct. 11, fifteen of the seventeen survivors (two recently recovered from blackhead not included) were injected rectally with virulent cultures of Histomonas, Strains B and D.	Aug. 23, one died, typical blackhead. Sept. 14, one died, typical blackhead. Up to Oct. 11, three other non-fatal cases of blackhead appeared. No case of blackhead subsequent to the test-inoculation.
From Lot III Twenty-five poults hatched June 30. Vaccinated with attenuated Strain A Histomonas in successive lots on various dates from July 3 to July 15 and reinjected on subsequent dates as necessary until infection was established as shown by microscopic examination of discharges.	July 15, one poult with a large diverticulum of gizzard was killed, showing no gross lesions of blackhead but microscopic invasion of the caecal mucosa. July 26, a runt with large yolk sac died showing peritonitis and caecal blackhead. Aug. 19, a poult died of progressive caecal blackhead of more than 3 weeks' duration. Another bird showing caecal induration recovered later on.	During last week in July, the twenty-two survivors were placed on contaminated soil. Oct. 1, all twenty-two survivors and on Oct. 11 all those not showing symptoms received rectal injections of virulent cultures of Histomonas, Strains B and D.	Sept. 30, one bird showed symptoms of blackhead but had recovered five days later. Between Oct. 7 and Oct. 21, ten cases of clinical blackhead appeared. All birds recovered although one was critically ill for several days. No sign of disease has subsequently appeared.

*That the poults of this group were from a poor hatch resulting from exposure to a period of high incubator temperature and were also exposed for two days to brooder house conditions, may account for their condition following vaccination.

(June 30th) lot, the test-inoculations resulted in ten cases of clinical blackhead, but every affected bird recovered.

Strain D, a more recently isolated strain of *Histomonas*, was employed in the late immunity test-inoculations. This was obtained on August 3, 1932 from the caecal discharges of a thirty-four day old turkey fed embryonated *Heterakis* eggs seven days previously.

The results of the vaccination of the above four lots of turkeys may be summarized as follows. In poults of Lot II, some of which had shown at an early age occasional cases of nonspecific caecal obstruction, and which had also been exposed for a time to brooder house environment, the inoculation of Strain A *Histomonas* has been attended with a high incidence of caecal disease. Metastasis to the liver, however, has rarely occurred as far as may be judged from fatal cases in these groups, and the caecal infection was also in general nonprogressive. The morbidity observed early in life in this group of birds is obviously not attributable to the vaccination alone, for the histological study of the tissues shows a much more intense inflammatory reaction than would be associated with so mild a degree of histomoniasis, if uncomplicated. The occurrence of pericarditis and peritonitis in the fatal cases also furnishes evidence of infection other than histomoniasis. If, however, Lot II is included in our figures on mortality due to vaccination and assuming that the poults that were killed would have otherwise died, there were eight deaths in the seventy-eight turkey poults thus far vaccinated (omitting one that died at the age of five days), or approximately ten per cent mortality. If Lot II is omitted on account of factors other than vaccination contributing to mortality, there was one death in fifty-two young turkeys vaccinated, or less than two per cent mortality from vaccination. Either of these figures is in marked contrast to nine deaths in ten turkeys, or 90 per cent mortality following inoculation with virulent strains of *Histomonas*, and the tenth turkey, while surviving the disease was permanently damaged to such an extent as to render it worthless.

The immunity of vaccinated young turkeys has been tested by the inoculation of virulent strains of *Histomonas* at various intervals up to eight weeks after vaccination, Table IX. There was one death in twenty-seven poults thus tested, or a mortality of 3.7 per cent attributable to the test inoculation, and in this case although there was progressive caecal disease, there was no liver involvement. Again these results may be compared with 100 per cent liver involvement and

90 per cent mortality in the control turkeys of the same lots inoculated on the same occasions with identical material.

That the protection conferred by the attenuated strain may be lost in the course of time is shown by the appearance of several cases of blackhead in turkeys two or more months after vaccination. Also when the immunity test-inoculations are postponed until several months after vaccination, partial loss of protection is indicated in the appearance within a fortnight after the test inoculation of cases of clinical but non-fatal blackhead. While it is probable that successive transient infections tend to build up immunity, it is believed, although not actually demonstrated in these experiments, that loss of immunity is preceded by loss of infection,—that is a discontinuance of the carrier state. That the infection may be lost is shown by the records of two cases of histomoniasis in laboratory-reared turkeys, in which *Histomonas* disappeared after a time from the caecal discharges, being no longer demonstrable by direct examination or by culture, and the caecal material proving noninfective when inoculated into normal birds. In histomoniasis, immunity is probably maintained at a high level on continuous exposure to infection, such as may be derived from soil sown with *Heterakis* eggs or from association with other infected birds of the flock.

The reinforcement of vaccination by test-inoculations of a virulent strain of *Histomonas* has resulted in an effective immunity which has withstood exposure to contaminated soil throughout the summer and autumn. An index of the contamination of the soil is furnished by the high incidence of the caecal worm, *Heterakis gallinae*, in experimental turkeys when prepared for market late in November,—1034 worms were obtained from the caeca of a single bird. In order to determine whether *Histomonas* had persisted in the flock up to this time, the embryonated eggs from *Heterakis* collected from a number of these turkeys were fed to young chickens. Blackhead followed the feeding of five out of eleven samples of *Heterakis* material from individual turkeys, proving that at least a large proportion of these apparently normal turkeys had remained carriers of virulent blackhead.

Attempted vaccination of mature turkeys.—Since a considerable mortality from blackhead is frequently observed in year-old turkey hens toward the end of the laying season, a group comprised of three males and sixteen females from the lots vaccinated early in life has been held over to the present season (1933). Opportunity was also taken to compare the effects on mature turkeys of vaccination against blackhead early in life with that attempted at maturity. Thus sixteen

turkey pullets were purchased on March 8, 1933, from a flock considered to be free from blackhead. The turkey raiser from whom these were obtained reared from ten to twelve thousand turkeys in the summer of 1932 and reported that he had observed no blackhead. A casual inspection of his flock on several occasions had revealed no birds with suggestive symptoms. Nevertheless no certain information is available as to the possible presence of avirulent *Histomonas* infection, although in view of the great numbers of birds congregated together without evidence of disease, this does not seem probable. Eight of these purchased turkeys were vaccinated with the attenuated Strain A *Histomonas* on March 9 and March 11, 1933. On account of the difficulty in obtaining caecal discharges from individual mature birds, and also in the recognition of *Histomonas* in the presence of swarms of other species of protozoa, no attempt was made to determine whether this organism became established in these birds. About a fortnight later, the eight vaccinated and the eight non-vaccinated control turkeys were added to the flock of nineteen birds vaccinated early in life and exposed henceforth to contaminated soil, including a tract spread thickly with poultry manure.

At the time of writing, July 31, 1933, there has been one death from undetermined causes from the nineteen breeding turkeys vaccinated early in life. Six of the eight vaccinated in March 1933 have died, the deaths of three of these being directly attributable to blackhead, and the scars of this disease contributing to the deaths of the other three. Three of the eight non-vaccinated controls have died, two from blackhead and one from other causes.

Thus the vaccination of turkeys at maturity has furnished no adequate protection while vaccination early in life with more or less continuous exposure thereafter to contaminated soil, has completely protected a flock of nineteen turkeys. Incidentally it is of interest that a considerable proportion of non-vaccinated adult turkeys survive for relatively long periods under conditions that would be promptly fatal to young turkeys. An explanation of this failure of the inoculation of Strain A *Histomonas* to protect mature turkeys is furnished by the results obtained in experiments carried out several months later on young chickens and turkeys.

Loss of immunizing properties under long cultivation.—Since it was not known to what extent Strain A had retained its immunizing properties during its third year under cultivation, a group of seven chickens inoculated on May 26, 1933, with this strain were subjected on June 24 to a test-inoculation with virulent Strain D isolated some-

what over ten months previously. All but one of these vaccinated chickens showed some degree of disease when killed six days later, but slight in contrast with that found in a series of eight non-vaccinated control chickens of the same hatch simultaneously inoculated with the same virulent strain and killed on the same date. The lesions of the most severely affected chicken of the vaccinated series were less extensive than those of the mildest case of the control non-vaccinated series. Thus while the caeca of all but one of the vaccinated chickens presented macroscopic lesions, they were nevertheless contractile and functioning. Those of the non-vaccinated chickens, which were diseased throughout, showed rigid non-contractile walls and in all except one bird were distended with large cores of exudate. Since no lesions of consequence were found the year previously in vaccinated chickens tested with virulent culture, it is clear that Strain A has lost some of its immunizing properties under continued cultivation. This may account for the failure of this strain to protect the mature turkeys vaccinated several months previously.

Virulence tests of different strains of Histomonas on day-old chickens.—In order to test the pathogenicity of the two strains of *Histomonas* isolated in culture during the year 1932, two groups of day-old chickens have been inoculated, one with Strain B of March 16, 1932, the other with Strain D of August 3, 1932. In each group, one bird was killed five days, one six days, and four seven days after inoculation. *Histomonas* became established in all these birds, but those inoculated with Strain B showed no lesions while those inoculated with Strain D showed extensive caecal disease and also minute liver lesions in three instances. At the same time, two groups of chickens were inoculated, one with Strain A and one with Substrain A 1, previously shown by earlier experiments to have become attenuated. In each group, three birds were killed at the end of seven days, one eight days, and one ten days after inoculation. With the exception of small opacities in one bird inoculated with Substrain A 1, none of these showed lesions, although *Histomonas* was established in all. Thus not only has the older Strain A with its Substrain A 1 continued to be non-pathogenic, but Strain B has apparently lost pathogenicity for chickens. Attention is called to the fact that a year previous to this, Strain B produced blackhead with liver involvement with great regularity.

Vaccination of young turkeys in 1933.—A commercial flock of fifty young turkey poults were inoculated with Strain A on May 31 of the present year, and during the three weeks following showed no manifestation of disease. Those in which *Histomonas* was not demon-

strated were reinoculated on June 6 and some again on June 10. On June 24, all fifty were rectally injected with cultures of Strain B which, as shown above, has lost much of its pathogenicity for chickens. From ten to fourteen days later, as many as eight of these birds showed loss of appetite, inactivity, and in most of these the caeca were found on palpation to be distinctly indurated. One poult died on July 14 and one on July 18, both from blackhead with a moderate number of liver lesions. One dying on July 25 showed focal caecal lesions and peritonitis. Two died with no indication of blackhead, and forty-five survive. The birds had promptly acquired considerable numbers of *Heterakis* as well as *Ascaridia* from their exposure to soil since June 9. The vaccination of this flock of turkeys was done for practical rather than for scientific purposes, and should not be regarded as a properly conducted experiment. The occurrence of typical cases of blackhead may be explained either through the acquisition of inadequately protected birds of a virulent strain of *Histomonas* from exposure to soil, or by the possibility that Strain B, while innocuous for chickens, is still pathogenic for turkeys. Hence additional inoculations were made in chickens and in young turkeys in order to test further the pathogenicity of Strain B.

Loss of virulence in a second strain of Histomonas.—Five chickens were injected rectally with Strain B cultures and three of these were killed after nine days, and two, eleven days later. One of the five showed foci of thickening of the caecal mucosa, but the caeca of the other four appeared normal. Young turkeys were also inoculated on the same occasion with Strain B and, with the exception of one which failed to become infected, all developed a mild form of histomoniasis with focal or generalized thickening of the caecal mucosa, but without ulceration or involvement of the liver. None of these showed symptoms and all grew normally up to the time that they were killed. Cores of exudate were present in several but were non-adherent. The disease was obviously nonprogressive in these turkeys and in several the process of repair was well advanced when the bird was killed. Data pertaining to the virulence tests of Strain B are furnished in Table XI.

It is evident from these inoculations that Strain B after sixteen months in culture now rarely produces lesions in chickens and is only slightly pathogenic for young turkeys. In the latter, it produces a mild nonprogressive disease of the caeca and has now lost most of its metastasizing qualities. Hence it seems probable that a progressive loss of virulence may take place with considerable regularity in *Histomonas* propagated in culture medium.

TABLE XI.
VIRULENCE TEST-INOCULATIONS OF STRAIN B AND STRAIN D HISTOMONAS, AFTER LONG CULTIVATION.

BIRD	AGE	INOCULATION	RESULT
C 8858	2 days	May 26, 1933, rectally injected with culture of Strain B Histomonas isolated March 16, 1932.	K. May 31. Normal, Histomonas present.
C 8859	" "		K. June 1. Normal, Histomonas present.
C 8860	" "		K. June 2. Normal, Histomonas present.
C 8861	" "		K. June 2. Normal, Histomonas present.
C 8862	" "		K. June 2. Normal, Histomonas present.
C 8863	" "		K. June 2. Normal, Histomonas present.
C 8864	2 days	May 26, 1933, rectally injected with culture of Strain D Histomonas isolated August 3, 1932.	K. May 31. Caeca extensively diseased.
C 8865	" "		K. June 1. Caeca extensively diseased.
C 8866	" "		K. June 2. Caeca extensively diseased, one liver lesion.
C 8867	" "		K. June 2. Caeca extensively diseased, minute liver lesions.
C 8868	" "		K. June 2. Caeca extensively diseased, two minute liver lesions.
C 8869	" "		K. June 2. Scattered and confluent focal lesions of caeca.
T 8928	6 days	July 17, 1933, rectally injected with culture of Strain B Histomonas isolated March 16, 1932.	K. July 26. Mild caecal disease* with core.
T 8929	" "		K. July 26. No infection.
T 8930	" "		K. July 26. Caecal lesions 3-8 mm.
T 8931	" "		K. July 28. Mild caecal disease with core.
T 8932	" "		K. July 28. Mild caecal disease, healing.
T 8933	" "		K. July 29. Small foci of infection in caeca.
T 8934	" "		K. July 29. Focal lesions of caeca, slightly adherent masses of exudate.
T 8935	" "	8 weeks	K. Aug. 7. No lesions, Histomonas present.
T 8936	" "		K. July 28. Extensive non-ulcerative caecal disease with cores.
C 8937	27 days	Same	K. July 26. Mild caecal disease.
C 8938	" "		K. July 26. Normal, Histomonas present.
C 8939	" "		K. July 28. Normal, Histomonas present.
C 8940	" "		K. July 28. Normal, Histomonas present.
C 8941	2 months	Same	K. July 26. Normal, Histomonas present.

* Mild caecal disease signifies either small focal lesions or thickening of caecal wall without ulceration.

DISCUSSION

Histomonas meleagridis in the course of long cultivation in association with the bacteria with which it is isolated apparently tends to lose virulence. Thus a strain (Strain A) of the organism, which for a time produced liver lesions as well as caecal disease in young chickens, has become non-pathogenic for both chickens and turkeys. A second strain (Strain B) of the protozoön which has been under cultivation for sixteen months, and also originally fully virulent, now rarely produces lesions in chickens and is only slightly pathogenic for young turkeys. Infection with a strain which has become non-pathogenic under cultivation has served to protect chickens and turkeys against blackhead, but after an additional year under cultivation, its immunizing properties appear to have diminished.

Virulent *Histomonas* may be readily obtained in culture from chicken carriers produced either by the feeding of *Histomonas*-bearing *Heterakis* eggs or by the rectal injection of liver lesions from acute cases of blackhead. By isolating such cultures at long intervals, as, for example, yearly, it is probable that strains may be made available that will show progressive loss of virulence and immunizing properties. The partial protection afforded by non-pathogenic strains may be reinforced by superinfection with pathogenic strains.

The advantages to be derived from the vaccination of turkeys early in life against blackhead are obvious. There is not only the factor of economy in the saving of labor, reduced outlay for feeds and for wire platforms and other equipment, but it is possible to afford conditions which are in the long run favorable to the development of a vigorous stock. Thus by rearing young turkeys on ground from early life, they exercise freely, are able to dust themselves, obtain more or less in the way of vegetable and mineral matter, and a certain number of insects. Occupation in foraging for green stuff and insects maintains a morale in a flock not often observed in platform-reared birds. Even though small losses may attend the procedure of vaccination, such are to be preferred to the loss of similar numbers later in life. However, while adequate protection may be afforded when vaccination is carried out under laboratory conditions, as shown by the results of the present investigation, unfortunately there are serious obstacles to employing vaccination in a commercial way. Thus difficulty is encountered at once in the matter of distributing attenuated cultures, for *Histomonas* will not survive in culture at ordinary room temperatures. While there are means of overcoming

this difficulty, there is the element of uncertainty in producing infection even when each bird is carefully injected with *Histomonas* culture. The inoculation of turkeys is apparently less uniformly successful than the inoculation of chickens. In order to produce an effective immunity, the vaccination with an attenuated culture should be followed in several weeks by the inoculation of a virulent culture. The gradual loss of the immunizing properties of the first attenuated strain studied also indicates that continued isolations at intervals of strains of *Histomonas* would be necessary in order to have cultures on hand that are non-pathogenic but nevertheless possess immunizing properties. Furthermore, even an attenuated strain may be regarded as potentially harmful to poults of low vitality or those that are in any way abnormal. Unless these obstacles are in some way overcome, the vaccination of blackhead may not be expected to be placed on a practical basis.

The prompt development of an effective protective reaction as the result of infection with an attenuated strain of *Histomonas* was quite unexpected and appears to be an unusual phenomenon in protozoan infection. However, this immunity has certain features in common with that found in many other protozoan infections in that it apparently requires the presence of the protozoön, that is the carrier state, for its maintenance and tends to disappear with the loss of infection. Further studies are essential in order to determine the nature of this immunity, but such observations as have been made indicate that it is based on a change in respect to the local reaction of the host tissues to the invading protozoön.

The hypothesis of Graybill and Smith (1920) that the development in the caeca of large numbers of *Heterakis* may lower the birds' resistance and so favor the invasion of the tissues by the protozoön may be reconsidered in connection with the exposure of the carriers produced by vaccination, to heavy infestations of the worm. The study of material derived from a considerable number of chickens first vaccinated by the rectal injection of cultures of attenuated *Histomonas* and later fed *Heterakis* eggs, has shown that the developing worms may produce punctate hemorrhage and exudate, in some instances in sufficient amount to fill the blind end of the caeca, but in no such instance has any invasion of the tissue of the immunized bird by *Histomonas* been found. Two vaccinated, young turkeys, see Table IX, 8702 and 8704, showed no symptoms,—one developed transient induration in the region of the caeca subsequent to the feeding of large numbers of *Heterakis* eggs, while two similarly fed

controls died of blackhead. Thus while there is ample evidence that the development of *Heterakis* is productive of injury to the caecal mucosa, and also that the protozoön causing blackhead may be introduced with the eggs of the worm, nevertheless the presence of large numbers of the developing worms has failed to produce acute blackhead in the carrier.

We have no definite information as to the extent to which the pathogenicity of *Histomonas* varies in nature. Certain observations made in the course of previous investigations indicate that relatively mild strains may occur. Thus it was found in our earlier investigations (Tyzzer and Fabyan, 1922) that the inoculation of the breast of the turkey with material from liver lesions of acute blackhead produced a progressive and uniformly fatal disease. Later on in a series of similar inoculations with liver lesions from another case, a considerable proportion of the breast lesions regressed and the birds fully recovered. The occurrence of mild strains of *Histomonas* in nature would also account for the occasional instances of the successful rearing of turkeys under surroundings that would appear obviously unfavorable.

SUMMARY

A strain of *Histomonas meleagridis* propagated in nutrient media in association with bacteria was demonstrated to be virulent after eleven months in culture but had lost its pathogenicity at the end of twenty-three months.

The immunizing properties of this strain against a recently isolated, fully virulent strain were demonstrated in the spring and summer of 1932 by experiments on young chickens and turkeys kept under rigidly controlled experimental conditions as well as by the practical test of rearing a vaccinated flock of turkeys for market under conditions in which non-vaccinated turkeys would not be expected to survive. This strain after another year in culture now only partially protects chickens against a virulent strain of *Histomonas*.

The inoculation of carriers, infected with an attenuated strain of *Histomonas*, with a virulent strain commonly results in the establishment of the latter in the caeca, or "superinfection."

The inoculation of the carrier with virulent strains of *Histomonas* not only probably reinforces its immunity but also furnishes a basis for the continued exposure to virulent infection necessary for subsequent freedom from disease.

Rapid passages of an attenuated strain of *Histomonas* through young chickens and turkeys have failed to restore its virulence.

The virulence of a *Histomonas* culture is found not to be dependent on the nature of the bacteria occurring in association with the protozoön but is a manifestation of the biological character of the latter, and is a quality which may be modified by long continued propagation in vitro.

A second strain of *Histomonas* isolated on February 27, 1932 and remaining fully virulent during the following summer, has lost much of its pathogenicity for young turkeys after sixteen months in culture and is almost wholly non-pathogenic for chickens. The third strain isolated August 3, 1932 was found to be fully virulent nearly ten months later.

On the basis of histological evidence, it appears probable that the immunity resulting from the inoculation of an attenuated strain of *Histomonas* is due to slight and non-progressive invasions of the tissues by the protozoön. Thus while macroscopic lesions seldom appear, the study of stained sections reveals *Histomonas* in such minute opacities as occasionally occur and in some instances in caecal mucosa that appears quite normal to the naked eye.

The suggestion is made that diminution in the immunizing properties of *Histomonas* under continued cultivation may be attendant upon a further loss of ability to invade the tissues. In the course of long cultivation, *Histomonas* appears not to have lost infectivity, i. e. ability to establish itself in the caeca of chickens and turkeys. No evidence has been obtained thus far that loss of virulence in *Histomonas* is attended with greater chronicity of disease, for young turkeys recover promptly from infections with a strain formerly virulent but at present only mildly pathogenic.

It is pointed out that serious obstacles interfere with the placing of the vaccination of turkeys on a practical basis.

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CRITICAL EXAMINATION OF PHYSICAL ANTHRO-
POMETRY ON THE LIVING.

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STATEMENT OF PROBLEM.

ANTHROPOMETRY is becoming a widespread practice. This is partly because of its importance in physical child development, and partly because of the relations which Kretschmer ('26) pointed out between body build and temperament in psychiatric state. Also, the comparative study of races by anthropologists depends largely upon anthropometry.

PART I. EXTRINSIC ERRORS IN ANTHROPOMETRY.

Anthropometric method is still far from being in a satisfactory state. Fortunately, we have standard apparatus and the difficulty does not lie here, although no doubt new kinds of apparatus will be eventually devised for the measurement of particular dimensions. The largest error perhaps lies in the determination of particular landmarks. This is a matter upon which Richard H. Post ('31) has published a study, after visiting many of the principal anthropometrists of this country and Europe.

A matter that has not been sufficiently investigated is the error due to differences in posture of the subject, dependent upon the time of day, and fluctuations depending upon the psychological and physiological state of the subject. The latter point particularly needs to be stressed. The muscles of the body indeed modify the distance between landmarks, and anthropometry is accordingly concerned partly with the neuro-muscular mechanism and tone of muscles. It is hardly an exaggeration to say that anthropometry is within limits a form of psychometry.

Finally, slight variation in technique due to differences in pressure applied to the skin overlying skeletal points, or in girths, has not been sufficiently considered. It is to be hoped that all of these variations in technique will be reduced through the activities of the Anthropometric Committee of the International Federation of Eugenic Organizations.

METHOD AND MATERIAL.

In order to get some light upon the differences in results due to variations in the subject and slight differences in technique (personal equations) a series of measurements was made by a single measurer (M. S.) on a single subject (R. M.), who was measured fifty consecutive times at different times of the day through a number of days. It was hoped to get answers to the following questions: (a) What variations occur in successive measurements by one person of one subject in a short period of time? These variations may be due to (1) differences in the neuro-muscular condition of the measurer, (2) variations of the neuro-muscular state of the subject. (b) What effect has the time of day? This was determined by comparing morning and evening measurements. (c) What effect on measurement has the clothing? This was investigated by having the same subject wear at one time a tightly fitting bathing suit and at other times the usual indoor clothing. The differences between the right and left sides of the subject were also studied.

The dimensions measured were (1) weight, (2) stature, trunk and appendages, (3) sitting height (spine in the same posture as standing), (4) biacromial width, (5) intercrystal width (skin hardly indented), (6) interspinal width (between middle points of anterior sup. il. spine), (7) transverse chest at fifth ribs, (8) antero-posterior chest diameter, (with straight armed calipers), (9) chest girth, perpendicular to spine at axilla, (10) acromial height, from floor, (11) radiale height, (12) styliar height, (13) dactylar height, from floor, (14) acromion to styliar, measured direct with calipers, (15) acromion to radiale, with calipers, (16) radiale to styliar, (17) span, subject with back to wall and anthropometer behind subject, (18) iliospinal height, (19) tibial height, (20) tibial to sphyriar, direct measurement, (21) hand length, from tracings, which averaged 8.7 mm. greater than direct measurement, (22) hand width, (23) foot length, (24) foot width, (25) upper arm girth, (26) lower arm girth, (27) minimum forearm girth, (28) wrist girth, (29) calf girth, (30) ankle girth. Head and face: (31) head girth, (32) neck girth, (33) head length, (34) head width, (35) bizygomatic width, (36) minimum frontal, (37) bigonial width, (38) nasion to subnasion, (39) nose breadth, (40) nose depth, (41) trichion to gnathion, (42) nasion to gnathion, (43) nasion to stomion, (44) pinna length, (45) pinna width, (46) outer eye angles, (47) inner eye angles, (48) mouth width, (49) lip thickness.

RESULTS.

A. VARIATIONS IN ACCURACY OF MEASUREMENTS.

Table I gives the summary of the results obtained by M. S. in measuring R. M. These results are measured by the inaccuracy of

TABLE I.

SHOWING THE RESULTS OBTAINED BY M. STEGGERDA IN MEASURING R.M.

DIMENSION	MEAN	σ	P.E.	C.V.
			SINGLE MEAS.	
Stature.....	1672.23 mm.	3.10 mm.	2.09 mm.	.19%
Head lgth.....	194.24	.43	.29	.22
Bizygomatic bdth.....	130.88	.32	.22	.24
Supst. Ht.....	1358.92	3.52	2.37	.26
Head Bdth.....	146.30	.46	.31	.31
Head Girth.....	572.84	1.86	1.25	.33
Span.....	1612.77	6.72	4.53	.42
Net arm lgth. (Subt.).....	523.80	2.42	1.63	.46
R. Acromion Ht.....	1362.00	6.38	4.30	.47
Acromion to Stylium.....	522.96	2.56	1.73	.49
Sitting Ht.....	905.08	5.36	3.62	.59
R. Foot (Direct).....	253.60	1.54	1.04	.61
R. Iliospinale Ht.....	910.31	5.70	3.84	.63
R. Radiale Ht.....	1065.85	8.14	5.49	.76
R. Tibiale Ht.....	441.36	3.37	2.27	.76
R. Stylium.....	836.15	6.48	4.37	.78
Neck Girth.....	320.34	2.57	1.73	.80
Weight in lbs.....	138.85	1.17	.79	.84
R. foot lgth. (Tracing).....	256.16	2.27	1.53	.89
Chest Girth.....	852.32	7.78	5.25	.91
Tibiale to Sphyrion Ht.....	359.92	3.29	2.22	.91
R. lower Arm Girth.....	231.70	2.21	1.49	.95
R. Dactylion Ht.....	662.77	6.36	4.29	.96
Bigonial Bdth.....	101.52	.98	.66	.97
Sitting Supst. Ht.....	589.08	5.96	4.02	1.01
Intercriatal Bdth.....	301.48	3.13	2.11	1.04
Trichion to Gnathion.....	180.44	1.89	1.27	1.05
Minimum Frontal Bdth.....	106.76	1.12	.76	1.05
Wrist Girth.....	144.32	1.53	1.03	1.06
Gross Arm Lgth. (Subt.).....	697.96	7.50	5.06	1.07
Vertex Ht.-Supst. Ht.....	312.84	3.56	2.40	1.14
R. Ankle Girth.....	209.12	2.47	1.67	1.18
Chest A.P.....	200.76	2.40	1.62	1.20

TABLE I. (Cont.)

SHOWING THE RESULTS OBTAINED BY M. STEGGERDA IN MEASURING R.M.

DIMENSION	MEAN	σ	P.E. SINGLE MEAS.	C.V.
Acromion to Radiale (Direct)	294.04	3.64	2.46	1.24
Chest transverse	271.08	3.50	2.36	1.29
R. Hand Lgth. (Direct)	172.50	2.26	1.52	1.31
Nasion to Gnathion	121.54	1.59	1.07	1.31
External Eye Angles	96.36	1.31	.88	1.36
R. Minimum Forearms	150.06	2.07	1.40	1.38
Radiale to Stylium (Direct)	227.96	3.26	2.20	1.43
R. Calf Girth	325.52	4.71	3.18	1.45
Waist Girth	734.96	10.81	7.29	1.47
R. Hand Lgth. (tracing)	181.24	2.70	1.82	1.49
R. Upper Arm Lgth. (Subt.)	296.92	4.53	3.06	1.53
Acromion Bdth.	353.56	5.46	3.68	1.54
R. Hand Breadth (Direct)	76.34	1.21	.82	1.59
R. Hand Breadth (tracing)	77.90	1.25	.84	1.60
Inner Eye Angles	33.82	.59	.40	1.74
R. Lower Arm Lgth. (Subt.)	228.28	4.45	3.00	1.95
Nasion to Stomion	78.34	1.53	1.03	1.95
Nose Bdth.	31.34	.65	.44	2.07
Trochanter Bdth.	346.48	7.42	5.00	2.14
R. Ear Lgth.	67.00	1.47	.99	2.19
R. Upper Arm Girth	273.96	6.15	4.15	2.24
R. Foot Bdth. (Direct)	88.16	2.07	1.40	2.35
Malleolus Ht.	74.72	2.04	1.38	2.73
Interspinal Bdth.	263.04	7.20	4.86	2.74
Nose Height	56.34	1.57	1.06	2.79
Mouth Width	49.14	1.47	.99	2.99
R. Foot Bdth. (tracing)	91.14	2.94	1.98	3.23
R. Ear Bdth.	34.04	1.13	.76	3.32
Nose Depth	27.64	1.31	.88	4.74
Lips	17.08	.84	.57	4.92
Nose Salient	20.84	1.50	1.01	7.20
Nose Bridge Ht.	14.68	1.65	1.11	11.24

the result; the least inaccurate, as measured by the coefficient of variation (C. V.), being placed at the top of the table. From this coefficient of variation it appears that some of the larger measurements, like stature, suprasternal height, span, sitting height, show variability mainly because the dimensions are large. And in these

cases the probable error in the measurement of a single dimension is often considerable. On the other hand, the highest coefficients of variation are generally for small dimensions as, for example, height of the nose bridge, with a coefficient of variation of 11%; the nose salient with a coefficient of variation of 7%; width of the lips with a coefficient variation of 5% and nose depth with a coefficient variation of 4.7%, and so on.

There are some measurements which have a small coefficient of variability despite the small dimensions. These must be regarded as essentially accurate measurements. Such are head length, bi-zygomatic breadth, head breadth, foot length, bigonial breadth, and minimum frontal breadth. On the other hand we found, as did Dahlberg ('26, p. 198), that some of the probable errors of measurement are small even when the dimensions are large, which indicates a high degree of precision in the measurement. For example, there is total stature, of which the probable error of measurement is only 2 mm., giving a coefficient of variation of .19%. Again, span gives a probable error of 4.5 mm., a variation coefficient of .42%. This is an inaccuracy somewhat greater than that of the stature on a mean measurement which is about the same, but this has an error of the single measurement of only 4.5 mm. out of a total of 1,613 mm.

Among the measurements that must be regarded as rather low in accuracy is the length of the lower arm as determined by subtraction from projected radiale height of projected stylium height from the floor. This has an average error of the single measurement of 3 mm., out of a total of 228 mm. In general, the lengths of the projections of the arm, as determined by measurements from the floor, have a low order of accuracy, or at least a large error for the single measurements. Also inaccurate are waist girth, chest girth, bi-acromial breadth, bi-crural breadth, trochanter breadth, interspinal breadth, sitting suprasternal height, upper arm girth.

The determination of arm length, by measuring from the floor, is inaccurate on account of the tendency of the shoulders to sway during the measuring. The accuracy of measurement of these dimensions of the arm can be increased if one begins by determining the right acromial height from the floor, measures the remaining points on the arm in rapid succession and then returns to the right acromial height. If the first and second acromial heights check within 2 mm. then the measurements as recorded are accepted as correct. If the second measurement of the right acromion is more than 2 mm. different from

the first the measurements are repeated, and so on until the difference does not exceed 2 mm.

The error in bi-acromial breadth is probably due partly to variations in posture of the scapulae (which are, of course, highly mobile), partly to variation of pressure upon the bony landmarks, and partly to variations in the manner in which the operator holds the calipers. Variations in intercrystal breadth are due in part to the fact that the landmarks are not defined points, but merely tangents to curves. Variations in sitting suprasternale heights are due in part to variations in general posture of the individuals and, above all, to the degree of inflation of the lungs, which modifies the suprasternale height. Variations in girth of the trunk are partly due to the act of respiration. At best these dimensions can be only an average of a number of measurements taken at different phases of respiration.

Trochanter breadth has a high inaccuracy which is a little difficult to account for. In interspinal breadth, error is due to the fact that the landmarks instead of being "points" are "knobs" and it is not always possible to determine the center of the knob. The error in right upper arm girth may be diminished by taking the girth always at a point where the belly of the bicep muscles are thickest, about half way between the acromion and the radiale.

B. REDUCTION IN HEIGHT FROM MORNING TO EVENING.

In the case of the 50 repeated measurements by M. S. on R. M. it appears that the following dimensions listed in Table II are most affected by the hour of the day at which they are taken:

TABLE II.

LIST OF DIMENSIONS WHOSE LENGTH IS MOST AFFECTED BY TIME OF DAY,
AND MEASUREMENTS MADE ON THEM.

DIMENSION	A.M.	P.M.	Δ	P.E. Δ	Δ /P.E. Δ
Stature	1672.23	1664.83	7.40	.57	12.98
Suprasternale Ht.	1358.92	1352.42	6.50	.80	8.13
Sitting Ht.	905.08	895.83	9.25	1.46	6.34
Sitting Supst. Ht.	589.08	581.50	7.58	1.92	3.95

The successive measurements of the same person at different times of the day showed, as we have seen, a loss in stature of 7.4 mm. from morning to afternoon and a loss in sitting height of 9.2 mm. in the same period. It might seem remarkable that the loss should be the

greater in the sitting height (involved as it is in stature). But anyone who has had extensive experience in measuring sitting height knows that the act of sitting, as contrasted with standing, brings quite new muscles to play upon the posture of the trunk and demands special control of, and tone in, those muscles. For we are habituated to erect standing and to a slumping sitting posture. The loss of stature during the day is probably quite as much due to loss of "tone" as of thickness of intervertebral pads.

This discernible loss of stature and sitting height has long been noticed. Nylin ('29, p. 35-37) and Boyd ('29, p. 394-396) have recently brought together the literature on this subject so it will not be necessary to review it again. Most authors find a decrease in stature of around 20 mm. from rising in the morning until bed time. In the present series of measurements, probably not more than 6 hours intervened between the first and second measurement; and there was a rest period (lunch hour) in the middle. Also the measurements were all made from 2 to 8 hours after rising in the morning; thus, in the middle of the day when change is least rapid.

C. UNSYMMETRICAL BODILY DIMENSIONS.

The following dimensions proved to be significantly unequal on the two sides of the subject. The average differences in mm. is given and the difference is also expressed in units of the probable error.

TABLE III.

MEASUREMENTS OF WHICH THOSE ON THE RIGHT SIDE ARE LESS THAN ON THE LEFT; WITH DIFFERENCES AND PROBABLE ERROR OF THE DIFFERENCE.

	Δ			Δ	
	mm.	P.E. Δ		mm.	P.E. Δ
Acromion to stylium					
(direct)	1.2	2.9	Upper arm girth	1.9	2.4
Acromion to radiale			Foot length (traced) . . .	1.6	4.8
(subt.)	4.5	8.9	Lower arm girth	1.6	5.3
Iliospinale height	14.4	13.9	Min. forearm girth	.9	3.0
Tibiale to sphyriion	4.0	10.2	Wrist girth	2.2	9.7
Hand length (traced)	4.4	12.1	Calf girth	2.7	4.1
Hand width (traced)	1.3	6.9	Ankle girth	3.6	11.2
Foot length (traced)	1.6	4.8			

D. EFFECT OF CLOTHING ON BODILY MEASUREMENT.

TABLE IV.

DIMENSIONS THAT ARE AFFECTED BY THE AMOUNT OF CLOTHING WORN:

	TIME	ORDINARY	BATHING	DIFFER-	P.E.D.	D/P.E.I
		INDOOR CLOTHING	SUIT	ENCE		
R. Acromion Ht....	A.M.*	1369.85	1362.00	7.85	1.27	6.18
Sitting Ht.....	A.M.*	909.85	905.08	4.77	1.33	3.59
Radiale Ht.....	A.M.*	1071.38	1065.85	5.53	1.74	3.18
Tibiale Ht.....	A.M.*	434.56	441.36	6.80	1.24	5.48
R. Styliion Ht....	A.M.*	841.69	836.15	5.54	1.56	3.55
R. Dactyliion Ht..	A.M.*	668.77	662.77	6.00	1.63	3.68
Sitting Supst. Ht.	A.M.*	594.62	589.08	5.54	1.62	3.42
Ankle girth.....	A.M.†	210.64	209.12	1.52	.47	3.25
	P.M.†					
Calf girth.....	A.M.†	329.20	325.52	3.68	.83	4.43
	P.M.†					
Trochanter bdth..	A.M.†	341.24	346.48	5.24	1.40	3.74
	P.M.†					

* 13 observations.

† 25 observations.

It is rather remarkable that so little difference was found between measurements of certain dimensions made on the skin (or tight fitting bathing suit) and over ordinary house clothing (without shoes). However, some measurements seemed to be seriously affected e. g. acromial height, tibiale height and calf girth. Since most of the dimensions listed in the foregoing table are little covered by clothing (except trochanter breadth) the differences are probably not due to the thickness of cloth but to an obscuration of the landmarks. Thus in acromial height the thickness of the dress over the shoulder is negligible, but since the point is difficult to locate with precision under the best of conditions the covering of the skin increases that difficulty—removes the aid of one sense (sight) in locating this landmark. Similarly, with the arm points. The radial “dimple” helps to locate radiale by sight, but hardly to touch. While it is gratifying to know that so accurate results can be obtained over clothing (as is so often necessary) for the most accurate comparative studies, as in growth studies in children, a minimum of clothing affords best conditions.

SUMMARY OF PART I.

1. Stature and sitting height were significantly greater in the morning than they were in the evening.

2. A woman's indoor clothing does not appreciably affect the significance of the measurement, but in several instances it does obscure the location of the point measured.

3. Tracings of hands and feet were significantly larger than measurements taken directly by calipers.

4. The diameters of the head are easily measured with a probable variation in repeated measurements of less than 1 mm.

5. Certain dimensions have a high variability with a probable error of single measurements of 5 mm. or more. These are: waist girth, chest girth, projective arm measurements taken from the floor, trochanter breadth (contour).

6. The results of most of these measurements show that this subject was significantly larger on her left side than on her right.

PART II. INTRINSIC ERRORS: THE PERSONAL EQUATION

Eleven adults were measured during morning hours between 9:30 and 11:30 o'clock by both C. B. D. and M. S. They were all measured in bathing suits. There were five men and six women. In each subject the dimensions were measured twice, all the measurements being made first upon a subject and then immediately repeated again on the same subject. During the interval the measurer had probably forgotten his findings at the first measurings.

Table V gives the percentage of inaccuracy of the different measurements made.* These are arranged in the first column in order of size as determined by M.S. Columns 4 and 5 give the findings of C.B.D. The mean differences in the findings of the two measures are given in column 2. That is, the first and second measurement for each of 11 subjects was averaged for each measurer (M.S. and C.B.D.). From the average for M.S. was subtracted the average for C.B.D. taking signs into account. The algebraic mean of these differences is thus given in column 2. They refer to the dimensions listed in column 1.

It will be observed that the measurements of M.S. are, on the whole, more accurate than those of C.B.D., which is probably in part

*Determined by dividing the quadratic mean of the differences x 100 by mean of measurements. Quadratic mean is the square root of the difference between each pair of measurements squared and summed for all differences ÷ number of individuals.

TABLE V.

ANALYSIS OF THE INACCURACY OF THE DIFFERENT MEASUREMENTS.

Col. 2. The average difference between the measurements of M.S. and C.B.D. for the dimensions in Col. 1.

Cols. 3, 4. Quadratic mean of differences divided by mean for meas. $\times 100$

1	2	3	4	5
DIMENSION				DIMENSION
Head Breadth	+ .32	.29%	.40%	Head Breadth
Stature	- .05	.43	.45	Maximum Head Girth
Head Length	+ 0.36	.48	.45	Sitting Height
Acromion Ht.	- 7.14	.50	.47	Stature
Radiale Ht.	-10.73	.55	.62	Span
Iliospinale Ht.	+ 3.68	.59	.71	Acromion to Stylium
Bizygomatic Bdth.	- 1.00	.61	.80	Nose Bridge Ht.
Maximum Head Girth	+ 3.64	.67	.81	Suprasternale Ht.
Acromion to Stylium	+ 6.23	.68	.81	Iliospinale Ht.
Trichion to Gnathion	+ 2.55	.70	.87	Ankle Girth
Sitting Ht.	- 2.00	.75	1.01	Acromion Ht.
Acromion to Radiale	+ 2.00	.75	1.04	Net Arm (Subt.)
Suprasternale Ht.	- 1.95	.78	1.04	Head Length
Stylium Ht.	-13.95	.80	1.10	Radiale Ht.
Minimum Frontal Bdth.	- 1.14	.80	1.10	Tibiale to Sphyrion
Span	- 4.45	.81	1.13	Chest Girth (Axillary)
Bigonial Bdth.	+ 1.50	.87	1.20	Bizygomatic Bdth.
Net Arm Lgth. (Subt.)	+ 6.77	.96	1.27	Radiale to Stylium
Neck Girth	- 2.05	1.04	1.34	Stylium Height
Ankle Girth	- 1.82	1.04	1.39	Sitting Supst.
Tibiale to Sphyrion	-12.55	1.22	1.60	Dactylium Ht.
Chest Girth (Axillary)	- 7.00	1.26	1.62	Tibiale Ht.
Upper Arm Girth	+ 3.73	1.32	1.66	Nasion to Gnathion
Radiale to Stylium	+ 0.95	1.33	1.71	Calf Girth
Dactylium Ht.	-16.14	1.37	1.73	Chest transverse
Calf Girth	- 1.68	1.41	1.82	Neck Girth
Minimum Forearm	- 3.09	1.45	1.87	Nasion to Stomion
Bi-acromion Bdth.	+ 5.82	1.49	2.00	Bi-acromion Bdth.
Lower Arm Girth	- 1.82	1.51	2.03	Bigonial Bdth.
Tibiale Height	- 2.77	1.52	2.06	Ear Height
Nose Bridge Ht.	- 1.86	1.59	2.14	Upper Arm (Subt.)
Lower Arm (Subt.)	+ 3.32	1.72	2.15	Minimum Frontal Bdth.
Nasion to Gnathion	+ 5.68	1.82	2.17	Vertex Ht. - Supst. Ht.
Chest transverse	-11.68	1.94	2.24	Dist. between ext. eye $\angle$
Upper Arm (Subt.)	+ 3.59	1.95	2.25	Minimum Forearm Girth
Lower Leg Length				
(Subt.)	-12.85	2.02	2.29	Acromion to Radiale
Upper Leg (Subt.)	+ 6.90	2.14	2.30	Lower Leg Length
Sitting Supst.	-10.00	2.17	2.34	Lower Arm Girth
Interocrisal Bdth.	- 0.86	2.17	2.41	Wrist Girth
Dist. bet. ext. eye $\angle$ s.	+ 5.64	2.20	2.43	Upper Arm Girth
Sitting Ht.-Sitting				
Supst	+ 8.00	2.31	2.46	Lower Arm Lgth. (Subt.)
Ear Breadth	+ 1.23	2.41	2.49	Trichion to Gnathion
Wrist Girth	- 1.10 $\pm$	2.58	2.49	Sitting Ht.-Sitting Supst

TABLE V. (Cont.)

ANALYSIS OF THE INACCURACY OF THE DIFFERENT MEASUREMENTS.

Col. 2. The average difference between the measurements of M.S.
and C.B.D. for the dimensions in Col. 1.Cols. 3, 4. Quadratic mean of differences divided by mean for meas. $\times 100$.

1	2	3	4	5
DIMENSION				DIMENSION
Chest A.P.	- 1.27	2.59	2.63	Upper Leg Lgth.
Vertex Ht.-Supst. Ht. . .	+ 1.82	2.60	3.02	Chest A.P.
Ear Height	- 0.45	3.10	3.32	Interspinal Bdth.
Inter. Malleolous Ht. . .	+10.40	3.27	3.34	Nasion to Sub
Nose Breadth.	+ 0.01	3.34	3.71	Nose Breadth
Nasion to Stomion . . .	+ 5.64	3.38	3.94	Inter. Malleolous Ht.
Dist. bet. intern. eye $\angle$ s	+ 1.80	3.82	4.10	Intercristal Bdth.
Mouth Width.	+ 1.73	3.89	4.24	Dist. bet. intern. eye $\angle$ s
Nasion to Subnasale . .	+ 5.18	4.42	4.31	Mouth Width
Interspinal Bdth. . . .	+ 7.41	6.39	4.82	Nose Depth.
Nose Salient.	+ 2.45	6.71	6.28	Ear Bdth.
Nose Depth.	- 0.05	6.88	7.59	Lip thickness
Lip thickness.	+ 0.59	9.25	9.22	Nose salient

TABLE VI.

AVERAGE OF DIFFERENCES BETWEEN TWO REPEATED MEASUREMENTS
OF THE SAME INDIVIDUAL.

DIMENSIONS	Average of the differences in millimeters			
	C.B.D.	M.S.	G.D.	S.D.
Head length.	1.55	.64	.51	.40
Head breadth.	1.18	.18	.54	.54
Frontal minimum diameter.	1.91	.73	1.38	1.25
Face breadth.	1.36	.64	.69	.44
Bigonial diameter.	1.64	.64	.65	.73
Face length.	3.70	1.00	1.52	1.36
Stature.	5.09	5.91	3.56	4.57
Sternal height.	8.55	9.18	4.25	5.39
Height of symphysis.	—	—	4.53	8.06
Height of acromion.	10.55	4.45	4.61	6.00
Height of tip of middle finger.	9.55	7.27	5.09	6.38
Length of arm.	4.90	3.73	4.03	6.41
Length of trunk.	3.36	6.09	5.83	9.09
Biacromial diameter.	5.73	5.00	3.31	2.99
Bicristal diameter.	9.73	4.73	1.64	1.81
C.B.D.	C.B. Davenport			
M.S.	Morris Steggerda			
G.D.	Gunnar Dahlberg			
S.D.	Mrs. G. Dahlberg			

accounted for by the fact that M. S. has been measuring continuous during some two hundred days of the year, whereas C.B.D. measures only during about thirty days of the year.

Table VI gives the average of differences between two repeat measurements of the same individual by the two measurers, C. B. and M.S.; and, in comparison, measurements made by G.D. and S.D., as recorded in the work of Dahlberg, 1928. This table shows that these absolute differences range from 0.2 to 10.55 mm. The smaller differences are obtained, of course, in head length and breadth and face breadth. The larger differences are, as would be expected, obtained for the most part in the larger dimensions such as length of trunk, height of acromion, height of tip of middle finger from the floor.

SUMMARY OF PART II.

1. The absolute inaccuracy of different measurements varies part directly with absolute size.
2. The percentage inaccuracy varies greatly. It is low in large dimensions, like stature; high in small dimensions, like lip thickness and nose dimensions.
3. The inaccuracy is partly inherent; due sometimes to the absence of sufficiently precise landmarks, sometimes to difficulty in securing uniform posture. Thus, waist girth, chest diameters, interspin width, intercrural width, length of arm and leg segments, suprasternal height (sitting) are among the least precise of the measurements.
4. There is a significant personal equation in the measuring by different anthropometrists, even those who have had similar training. This is due sometimes to differences in the "setting up" of the subject; sometimes to the use of slightly different landmarks; sometimes to subjective differences in the measurers.
5. As in other occupations so in measurement of the body continuous practice leads to increased precision.

DISCUSSION.

If there is to be a science of physical anthropology, attention must be focussed on methods of measurement. There must be agreement upon what to measure and how to measure, and there must be knowledge of the personal equation of the measurer.

A. TECHNICAL MATTERS WHICH NEED TO BE STANDARDIZED ARE:

1. The posture of the subject as a whole and in respect to each dimension measured. For example: How shall the subject sit in measuring sitting height? How shall he stand in measuring foot length? How shall the arm be held in measuring length of the lower arm?

2. The definition of landmarks. Many of these have been defined in Martin's ('28) textbook; but in many cases the definitions are far from adequate. For example, "Iliospinale ant., the most downwards directed point of the Spina ili. ant. sup." and "the Interspinal dimension is the straightline distance between the two iliospinalia ant. from each other." Now the iliac "spines" are 6 to 8 mm. thick and it makes a difference whether one measures to the lateral or the median surface of the spine. If one is to measure to the middle of the spine that constitutes a rough landmark. A score or more inadequate descriptions of this sort from Martin ('28) might be cited. All landmarks should be defined to within a millimeter or two.

3. The handling of moveable landmarks. Few of the landmarks commonly used are fixed. For example, thelion is defined as the center of the nipple. That would seem to be precise. But the nipple, in respiration, moves through a considerable arc and its height varies accordingly. The "at rest" position is not a thoroughly adequate definition: for the chest does move even at light breathing. Another instance: In measuring radiale to stylium how shall the plane of the hand lie in reference to the sagittal plane of the body?

4. The degree of pressure at the skin and tissues to be applied over bony landmarks. This is a topic which Miss Tildesley has stressed; and a tape has been devised with a spring to provide a standard tension. Such an instrument is slower to manipulate than an ordinary tape, and the error in posture and location of the girth to be measured are generally greater than that of skin pressure, e. g. the level for girth of upper arm, the maximum girth of lower arm, thigh girth, calf girth.

5. Alternative dimensions. There are frequently two or more ways to measure an organ. Agreement should be made as to standard dimensions. For example, the segments of the arm may be measured (in projection) from the floor or directly with the large calipers ("Stangenzirkel"). Again, thigh girth may be measured at gluteal fold or just below or wherever is maximum girth.

6. Alternative techniques. The handling of the instruments to

determine the dimensions. This is a somewhat complex subject, involves (1) the best instrument to use, (2) the best way to apply. For example, foot length may be measured with the anthropometer as calipers, the foot free; or with the depth measurer, heel applied to wall or box; or the contour of the foot may be traced on paper with a split pencil and this outline measured. This latter gives a *record* of the form of the foot, but the dimension of the outline tend to be 2-mm. too great.

B. CHECKING OF MEASUREMENTS.

a. Repetition. A single measurement of any dimension has a very limited value because of limitations in accuracy in making the measurement, because of possible imperfections or errors in finding landmarks, in reading the measuring scale, in recording, etc. Not until the whole set of observations has been repeated can one judge how accurate, or how inaccurate, the first set of observations may be. In our own measurements we have always taken stature three times in quick succession, each time warning the subject to stand straight. The largest of the satisfactorily determined measures obtained is used as the stature of the individual. Since stature is used in many indices it is essential that it should be as nearly correct as possible. If one has the opportunity of making frequent remeasurements of the same individual, usually a growing individual, each successive measurement serves as a rough check upon each other. We do not feel that any set of measurements taken on an adult is entirely trustworthy until it has been repeated.

A fairly satisfactory method of checking any bilateral organs is making measurements on both sides of the body. If the asymmetry appears marked then the measurements should be rechecked. Organ in the sagittal plane can sometimes be measured on both sides of the plane. Thus nose depth is determined by measuring the depth of the nose both from the right cheek and from the left; similarly the depth of the nose bridge from the inner angle of the eye is measured both on the right side and on the left side, and the average of the two measurements taken.

b. A second method of checking measurements is by securing the size of the dimension by two or more methods. For example, head height can be measured either with the head height instrument or by subtracting trignon height from vertex height. If findings by the two methods do not agree, it is necessary to find out why and remeasure until they do agree. Similarly, nose salient may be measured d

rectly from the upper lip, or the salient may be obtained by use of the depth measurer with the occiput against the wall and subtracting the distance: upper-lip-from-the wall from the distance tip-of-nose-from-the wall. If the results of the two methods of measuring are dissimilar they should be repeated until alike. The foregoing are examples of principle of checking which deserves to be widely adopted. Again, the length of the different segments of the arm may be obtained by measuring the distance from the floor of the critical landmarks: acromion—radiale—stylium. Owing to the fact that the acromion is very mobile it is desirable after the heights of the landmarks have been determined (starting with the acromion and proceeding to stylium) to check again on the acromial height to see that the subject has not moved in the meantime. Also, the measurement should be made on the left arm as well as on the right and the findings of the two arms should ordinarily be fairly close.

Of course the segments of the arm should be measured directly. These findings serve as a rough check on the measurements indirectly from the floor, but the measurements will not agree precisely because the measurements from the floor give projections of the length of the segments of the arm, and where the arm can not be straightened the projection may be much less than the true distance.

Every effort should, of course, be made to avoid errors, but a certain degree of error is inevitable. There are errors in the posture of the individual, errors in angular positions of the instruments, errors in reading of the instruments due to imperfect light or owing to bad illumination which may throw the reading at least 1 mm. out; blunders in calling off numbers in poor light as, for example, confusing a 3 and an 8, errors in hearing and recording. The principle has to be kept in mind, as stated above, that a single set of measurements has an unknown value.

c. Securing the comparability of the measurements of different operators and determining their personal equations. It is depressing to recognize that there are scores of anthropometrists in different parts of the world measuring by more or less different landmarks, with widely different techniques and publishing results without defining their technical methods. The consequence is that the published results of different authors cannot be closely compared, also these measurements are for the most part taken without checking so that the value of the determinations cannot be determined.

The only way, apparently, to secure the comparability of methods

is through the Congresses where a number of anthropometrists meet and agree upon the technical details necessary to secure that comparability.

C. CHANGE IN DIMENSIONS ASSOCIATED WITH SEASON.

Although our special data did not involve changing seasons for the sake of rounding out the subject the effect of season has to

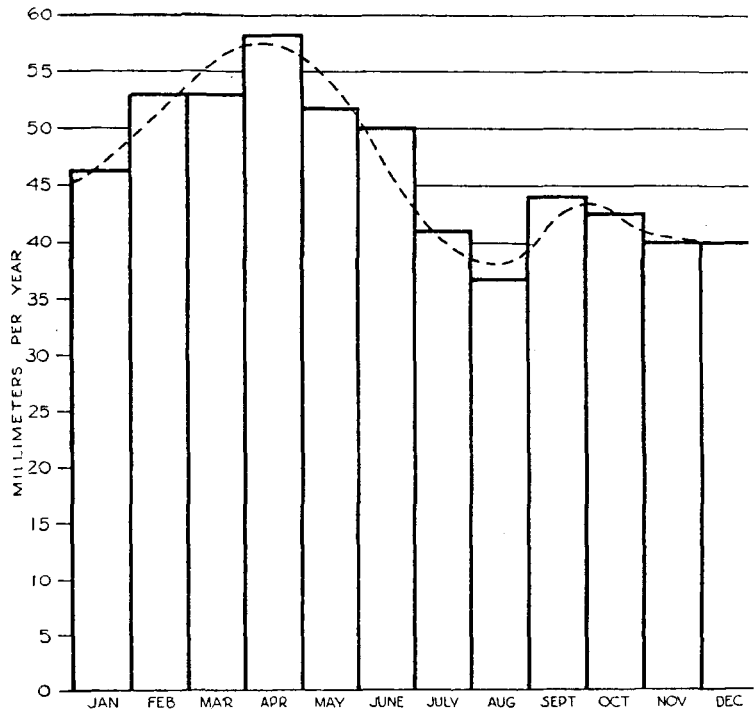


FIGURE 1. Increases for each month in stature centered at middle of crement period and calculated on a yearly basis. (LVD II ♂)

considered. The topic, far from new (see Nylin, '29), is of more than academic importance in the study of the growth of children who are measured repeatedly at different months of the year. Our contribution to this subject is based on studies of children, mostly at Letworth Village, measured repeatedly mostly at 6-month, sometimes

4- or 3-month, intervals. We shall consider here only stature and weight.

a. *Stature.*

Our data permit two methods of judging the influence of season. One is that of comparing the increments made during certain periods calculated on a yearly basis, and assigning such increments to the central month of the period. Thus, if a boy was 1342 mm. tall in

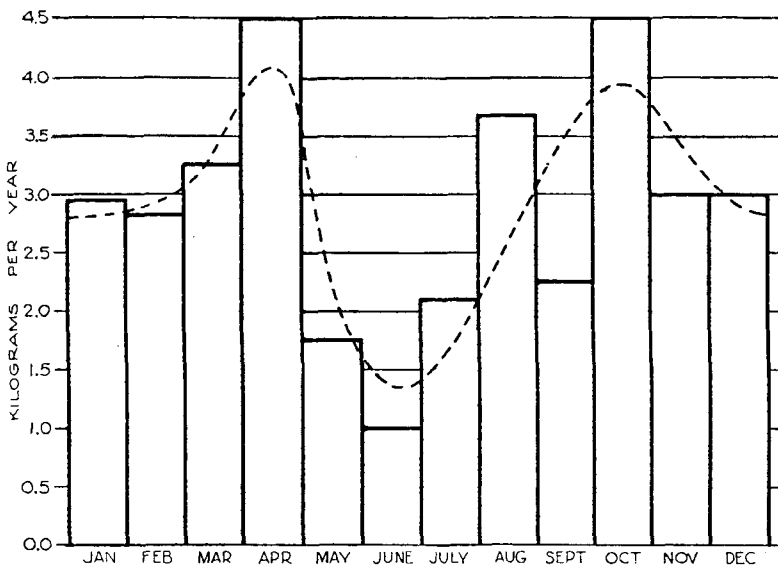


FIGURE 2. Increases, month by month, in weight, centered at middle of increment period and calculated on a yearly basis. (LVD II ♂)

October and 1370 mm. tall in the following April, he had increased 28 mm. in 6 months, or at the rate of 56 mm. per year, and this increment was assigned to the month of January. When all the assignments had been made, the median rate per year was calculated for each month.

The results are shown in Fig. 1. These results indicate that, on the average, stature makes its greatest gains, with us, in the spring of the year and its least gains in late summer. This result agrees with the findings of Camerer (1893), Schiötz (1922) A. and K. E. Schreiner (1922) and G. Nylin (1929); not so well with those of Porter (1920).

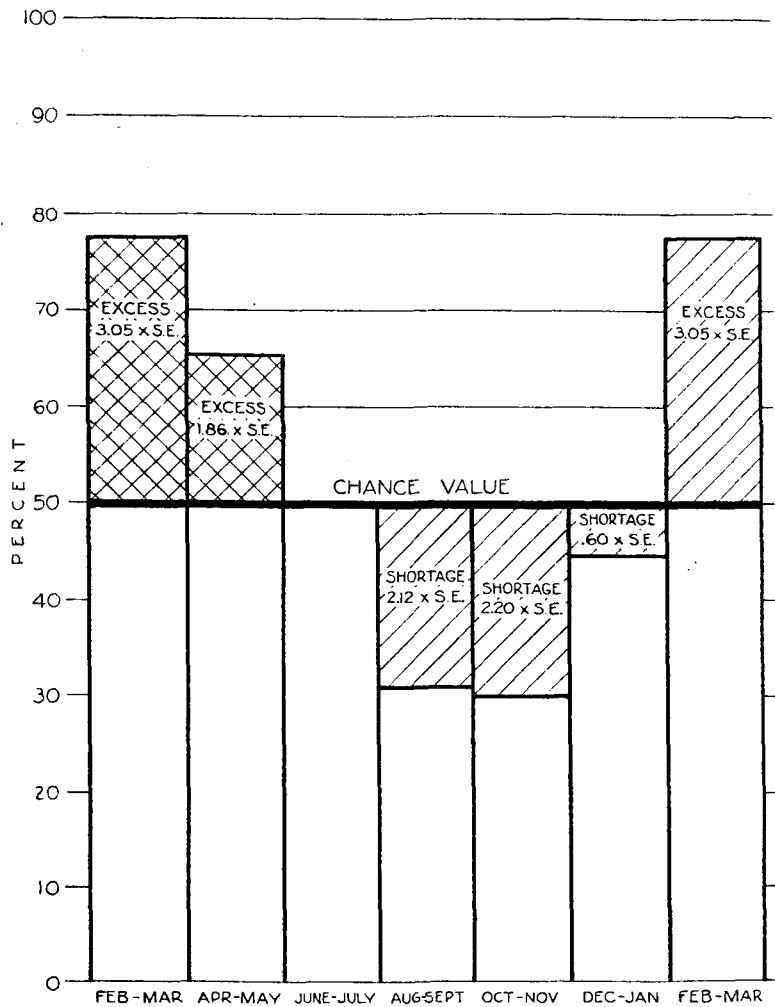


FIGURE 3. Departure from chance values of frequency of peaks of statur growth in different months. The significance of the difference between the number of peaks and depressions occurring in each bimonthly period was four by computing the standard error of the difference between the actual values and the chance values. (LVD σ^2).

b. *Weight.*

The results for body weight are given in Fig. 2. This shows two main periods of increase of weight, one in the spring corresponds to the period of increase in stature; the other in the autumn corresponding to a slight increase in stature that occurs at that time. The period of least increase in weight comes in June, while that of least increase in stature is in August. This suggests that growth in weight is more quickly disturbed by summer conditions than growth in stature. Also it appears that weight increases heavily (on the average) in the autumn, but the rate of growth of stature is relatively little accelerated at this time. This agrees with the findings of Nylin (1929) and of Palmer (1933).

The slowing up of weight-increase in the summer at Letchworth Village must be considered in relation to the activities of the children at that time. This is the period when the boys engage in work in the fields, some of it quite hard, at least a favorable change from the indoor work or relative inactivity of the winter and early spring.

The increase in weight of the autumn is perhaps a physiological preparation of the body for protection against winter cold. Since stature shows no great spurt at this time body build must increase.

The other method employed was that of counting the number of peaks and depressions of stature (or weight) occurring in each bi-monthly period and comparing them with chance equality. The results in bi-monthly periods are given in Fig. 3. This indicates that the spurts of growth are more apt to be centered in the spring months than in the autumn months. Thus this second method confirms the first.

We conclude then that growth in stature in our series is most rapid in the spring; while growth in weight is most rapid at the same time and also hardly less so in the autumn. There is a physiological need for autumnal acceleration in weight that hardly exists for stature.

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THE VOLUMES OF UNIT MASS OF LIQUID WATER AND
THEIR CORRELATION AS A FUNCTION OF PRESSURE
AND TEMPERATURE.

PART III. STEAM RESEARCH PROGRAM.

BY LEIGHTON B. SMITH AND FREDERICK G. KEYES.

(Contribution from the Research Laboratory of Physical Chemistry,
Massachusetts Institute of Technology, No. 326.)

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1. INTRODUCTION.

THE apparatus and procedures employed at the Massachusetts Institute of Technology in measuring the specific volume of liquid water have already been fully described in another paper.² It need only be stated here that the sample of fluid under investigation was distributed between two containers connected together by a steel capillary tube of small bore. The major portion of the water sample, from 75 to 99 percent of the total, was enclosed in the heavy walled metal container or "bomb" immersed in the high temperature bath. The remainder of the water was kept at a constant temperature of 30° C. in a steel cylinder over mercury and in the connecting capillary tube, part of which was at 30° C. and part at the higher temperature of the nitrate bath. The temperature gradient of the water in the capillary was made as sharp as possible by means of a water cooler placed on the tube just above the point where it emerged from the high temperature bath.

By means of the calibrated volume displacement piston (Fig. 9, p. 542, Part I) varying quantities of water could be displaced from the steel cylinder at 30° C. and forced over into the high temperature container. From a knowledge of the constants of the apparatus it was possible to calculate the volume occupied by that portion of the water sample at 30° C. and combined with the previously determined

¹ The present paper is the third of a series reporting the results of the Massachusetts Institute of Technology program of steam research promoted by the American Society of Mechanical Engineers through the material support of the steam power industries.

² F. G. Keyes, Part I. Proc. Am. Acad. Arts and Sci., 68, 505 (1933).

30° compressibility, it was possible to calculate the mass of water so confined. Such a small quantity of water was subjected to the temperature gradient in the capillary that it was not difficult to evaluate its mass with sufficient accuracy.

Thus, from the known total weight of the sample, the quantity at the high temperature was easily found. Knowing the volume at 0° C. and one atmosphere pressure, and the temperature and pressure dilation of the container, the total volume of water could be calculated for the temperature and pressure in question. It was thus a simple matter to compute the specific volume of the water for the temperature and pressure of the experiment.

During the course of the steam investigation, three independent series of measurements of the compressibility of liquid water were made. The first was carried out in the number 1 nickel cylinder and covered the temperature range from 30° to 300° C. A second series made in the number 1 A chrome-vanadium cylinder covered the range from 150° to 360° C. For the third and final series, the number 1 B Nirosta 18/8 cylinder was employed and a temperature range from 30° to 374° C. inclusive was covered. In all three series pressures were extended to more than 300 atmospheres.

The experimentally determined specific volumes are tabulated in a later section of this paper where they are compared with corresponding volumes calculated by means of an empirical equation relating volume to pressure and temperature.

2. FORMULATION OF THE LIQUID ISOTHERMS.

As an aid in correlating and smoothing the measurements it seemed desirable to attempt a formulation which would give a faithful representation of the liquid volume data. Such an equation would moreover have great usefulness in the preparation of volume tables and would serve as a valuable basis for calculating derived quantities.

Throughout the course of the steam investigation, experience indicated numerous refinements of apparatus and technique which were incorporated as the work progressed. It was therefore assumed that the third and final series of liquid volume measurements would prove superior both in absolute and relative accuracy and might be used alone as the basis for formulation. The results, as later set forth, appear to justify this somewhat arbitrary choice, indeed it seems safe to say that consideration of all the data could not have altered the final result materially.

Up to about 200° C., the liquid isotherms may be represented with a high degree of precision by an equation of the form:

$$v = v_s + a (p - p_s) + b (p - p_s)^2$$

where v = volume at the pressure p

v_s = volume at saturation pressure p_s^*

a, b = constants determined for each isotherm.

This form of equation may be used successfully for another hundred degrees by adding a term in the third power of $(p - p_s)$. Above 300° C., however, it was soon apparent that a more complicated function would be required to fit the increasing curvature of the isotherms.

After the trial of numerous types of equation, it was found that one of the form:

$$v = \frac{v_s + B (p - p_s) + D (p - p_s)^2 + E (p - p_s)^{1/2}}{1 + C (p - p_s)} \quad (1)$$

would represent the individual isotherms from 30° to 360° C. inclusive, with a high degree of precision. The constants, including v_s , were determined for each isotherm by the method of least squares. The values of v_s resulting will be referred to as the "experimental" or "observed" saturation volumes.

3. FORMULATION OF THE TEMPERATURE FUNCTIONS.

It now remained to represent each of the constants in equation (1) as some function of temperature.

The following equation:

$$v_s = \frac{v_c + a (t_c - t)^{1/3} + b (t_c - t) + c (t_c - t)^4}{1 + d (t_c - t)^{1/3} + e (t_c - t)} \quad (2)$$

where v_c = critical volume = 3.197500 cc. per gram.

t_c = critical temperature = 374.11° C.

t = temperature in degrees C.

$a = -3.151548 \times 10^{-1}$

* Footnote. Throughout this paper, saturation pressures used were those calculated from the M. I. T. vapor pressure equation. Loc. cit.

$$b = -1.203374 \times 10^{-3}$$

$$c = +7.48908 \times 10^{-13}$$

$$d = +1.342489 \times 10^{-1}$$

$$e = -3.946263 \times 10^{-3}$$

gave an excellent representation of the saturation volumes. Here again, as in fact throughout this work, all constants, including v_s , were determined by the method of least squares. The average deviation of the values of v_s calculated by equation (2) from those obtained by the isotherm equations was about one part in 7900, excluding only the value at 350° C. and those above 360° C. The deviation at 350° C. was about one part per thousand. Calculated and "observed" saturation volumes are given in Table I.

The calculated values for v_s were now substituted in the solution of the normal equations for the separate isotherms and values for the constant E determined.

These values of E were smoothed by an equation of the form:

$$\log_{10} (-1/E) = a + b(t_c - t)^{1/2} \quad (3)$$

where $a = +4.127788 \times 10^{-1}$

$$b = +3.999207 \times 10^{-1}$$

The smoothed values of E were then substituted in the normal equations and the remaining constants D , B and C were successively determined and smoothed by appropriate equations as follows:

$$\log_{10} (-D) = a + b(t_c - t) \quad (4)$$

where $a = -4.9573810$

$$b = -2.9752567 \times 10^{-2}$$

$$\log_{10} B = a + b(t_c - t)^{1/2} + c(t_c - t) + d(t_c - t)^{3/2} \quad (5)$$

where $a = -1.2925743$

$$b = -9.7238056 \times 10^{-2}$$

$$c = -1.2938329 \times 10^{-2}$$

$$d = +5.8890279 \times 10^{-4}$$

$$\log_{10} C = a + b(t_c - t)^{2/3} + c(t_c - t) + d(t_c - t)^{3/2} \quad (6)$$

where

$$\begin{aligned}a &= -1.6141307 \\b &= -5.2849209 \times 10^{-2} \\c &= -6.9720421 \times 10^{-3} \\d &= +4.5803994 \times 10^{-4}\end{aligned}$$

4. AGREEMENT OF CALCULATED WITH OBSERVED VOLUMES.

The observed specific volumes of liquid water for the three series are presented in Table II, together with the corresponding calculated values and average differences expressed in per cent. The equation is seen to represent all measurements of the stainless-steel series (Container 1 B) from 30° to 360° C. inclusive with an average deviation of one part in 3450, or excluding the 350° isotherm, to one part in 4710.

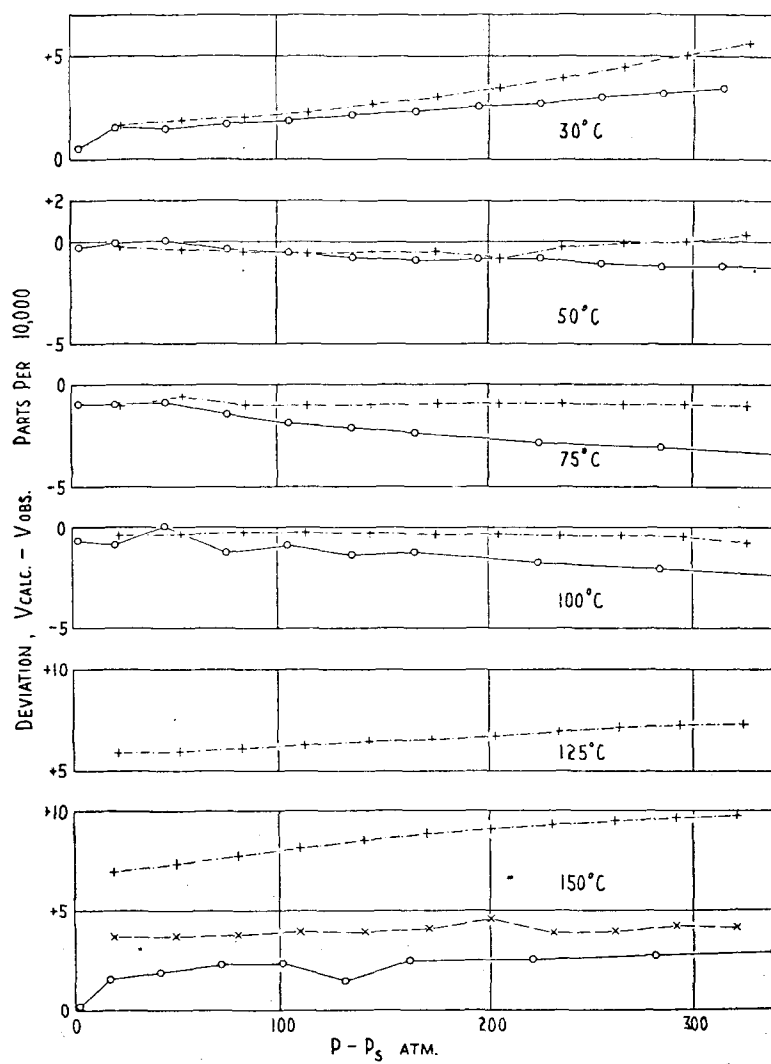
The average deviation from the calculated volumes of all measurements of the chrome-vanadium series is one part in 2120, or excluding those at 350° C., one part in 2540.

The average difference for all points in the nickel series, except those at 300°, is one part in 3330.

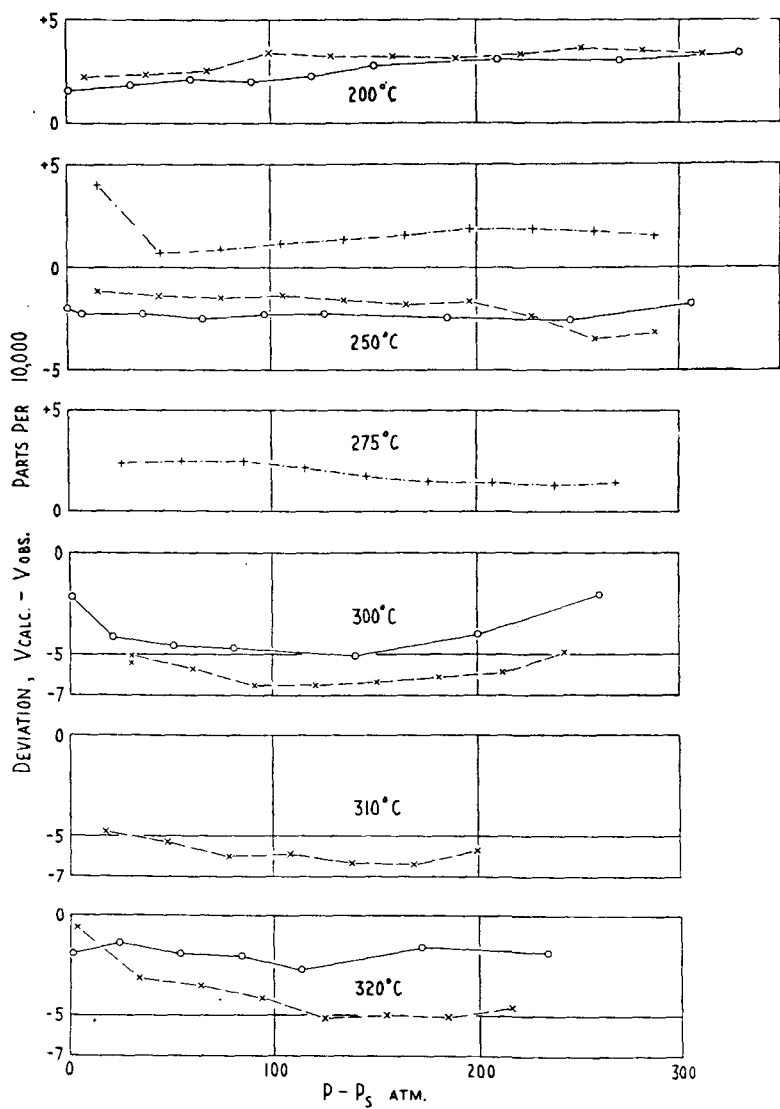
5. AGREEMENT OF THE MEASUREMENTS OF THE THREE SERIES.

The agreement between experimental results of the different series can best be shown by reference to the deviation plots, Fig. 1. Differences, in parts per ten thousand, between calculated and observed volumes are plotted against the pressure minus the saturation pressure for each temperature at which observations were made. With the exception of a few points close to saturation, all values for the stainless and chrome-vanadium series are seen to be consistent to better than a part in 3000. The average consistency appears to be considerably better than a part in 5000 and perhaps as great as a part in 7000 or 8000.

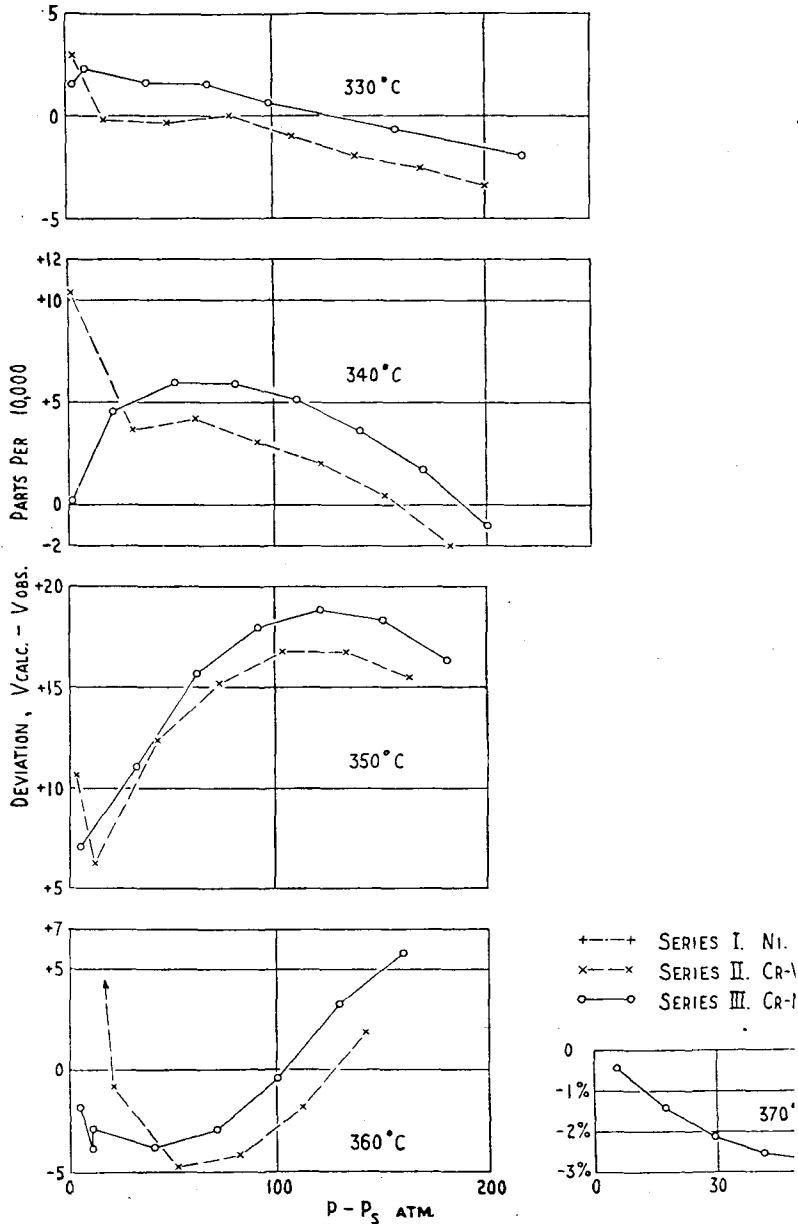
Up to 100° C. the measurements made in nickel are in excellent agreement with those made in stainless steel, maximum differences at the higher pressures amounting to about one part in 5000. At low pressures the agreement is better than one in 10000. At 150° and 250° C. the nickel series exhibit differences from the other measurements of a part in 2000 or 3000 and at 300° C., the highest temperature measured in the nickel run, the differences are about one part in 250.



SECTION A. FIG. 1.



SECTION B. FIG. 1.



SECTION C. FIG. 1.

6. COMPARISON WITH THE MEASUREMENTS OF OTHER OBSERVERS.

Of the numerous workers who have made a careful study of the compressibility of liquid water, Amagat³ alone covered a range of temperature and pressure appreciably overlapping that of the present study. The noteworthy measurements of Bridgman⁴ at temperatures from 0° to 95° C. were made with such large pressure increments, 500 atmospheres, that comparison with the present work would involve somewhat uncertain interpolation which has not been attempted. Richards and Stull⁵ measured the compressibility of water at 20° C., a temperature for which we have no direct experimental observations suitable for comparison. Tyrer⁶ reports compressibility coefficients at temperatures from 0° to 100° C. calculated from measurements of the adiabatic compressibility between one and two atmospheres pressure. These have not been compared with the M. I. T. data.

Measurements of the specific volume of water made by Trautz and Steyer,⁷ though covering approximately the same range of pressure and temperature as that of the present work, are possibly subject to considerable error according to Jacob⁸ who has made a critical survey of recent steam data. No attempt has been made, therefore, to use their results for comparison purposes in this paper.

The volumes given by Amagat at 30°, 50° and 100° C. have been compared in Table III with the results obtained at the Massachusetts Institute of Technology. It will be seen that maximum differences amount to one part in 4000 with an average difference of one part in 7930 for the three temperatures.

7. COMPARISON OF THE M. I. T. SATURATION VOLUMES ABOVE 100° C. WITH RESULTS OF OTHER OBSERVERS.

Measurements of the saturation volume of liquid water above 100° C. have been made by Ramsay and Young,⁹ J. J. Watterston¹⁰ and

³ Amagat, *Ann. de Chim. Phys.*, (6) **29**, 68 and 505 (1893).

⁴ Bridgman, *Proc. Am. Acad. Arts and Sci.*, **47**, 439 (1912). *Proc. Am. Acad. Arts and Sci.*, **66**, 185 (1931).

⁵ Richards and Stull, *J. Am. Chem. Soc.*, **26**, 399 (1904).

⁶ Tyrer, *J. Chem. Soc. London*, **103**, 1675 (1913).

⁷ Trautz and Steyer, *Forsh. Gebiete Ingen.* **2**, 45 (1930).

⁸ Jacob, *Engineering*, July-December (1931).

⁹ Ramsay and Young, *Phil. Trans. (A)* **183**, 108 (1893).

¹⁰ Watterston, *Phil. Mag.* (4), **26**, 116 (1863).

G. A. Hirn.¹¹ Values found in the various physical tables have usually been obtained from the results of these workers by some process of smoothing or averaging. For purposes of comparison, observed volumes reported in the literature are listed in Table IV with the M. I. T. calculated volumes for temperatures at and above 100° C. It will be noted that the differences are often quite large and in general rather erratic.

8. SPECIFIC VOLUME TABLE.

Calculated specific volumes of liquid water from 0° to 360° C. and pressures up to 350 atmospheres are presented in Table V.

9. DERIVATIVES OF VOLUME WITH RESPECT TO PRESSURE AND TEMPERATURE.

Differentiation of the liquid volume equation with respect to pressure at constant temperature gives:

$$\left(\frac{\partial v}{\partial p}\right)_T = \frac{B + 2D(p - p_s) + 1/2E(p - p_s)^{-1/2} + CD(p - p_s)^2 - Cv_s - 1/2CE(p - p_s)^{1/2}}{1 + 2C(p - p_s) + C^2(p - p_s)^2} \quad (7)$$

From this equation, derivatives were calculated for even temperatures and pressures. These are presented in Table VI together with the derivatives at saturation which were obtained by a process of graphical extrapolation from pressures not far above saturation.

Due to the complicated nature of the temperature functions of the liquid volume equation it was not practical to differentiate with respect to temperature. Accordingly, the derivative $\left(\frac{\partial v}{\partial T}\right)_p$ was obtained by applying the method of Rutledge¹² to the tabulated volume values of the derivative, so calculated, may be found in Table VI. Graphically extrapolated values for saturation are also listed.

10. LIMITATIONS OF THE LIQUID VOLUME EQUATION.

In the temperature range from 0° to 340° C. inclusive and up to pressures of 350 atmospheres, the liquid volume equation may be trusted to represent the behavior of liquid water to at least one part in 2000.

¹¹ Hirn. Ann. de Chim. Phys., (4) 10, 32 (1866).

¹² G. Rutledge, Physical Review, 40, 262 (1932).

The equation represents the volume at saturation, as determined from the M. I. T. measurements, to better than one part in 3000 up to and including 340° C.

The equation gives a minimum volume between 0° and 10° C., in qualitative agreement with the known behavior of water. The calculated saturation volume at 4° C. is 1.000218 cubic centimeters per gram, equivalent to a volume of 1.000145 millimeters per gram at one atmosphere, a difference of one part in 6900 from the accepted value.

The calculated compressibility coefficient, $\frac{1}{v} \left(\frac{\partial v}{\partial p} \right)_T$, shows a minimum at about 30° C., likewise in qualitative agreement with the observed behavior of water.

The equation demands an infinite compressibility at saturation for all temperatures since differentiation with respect to pressure at constant temperature (Eq. 7) gives a term, $1/2E(p - p_s)^{-1/2}$, becoming infinite when $p = p_s$. As previously noted, a finite value of the derivative at saturation, was obtained by graphical extrapolation.

No significance can of course be attached to an infinite compressibility at saturation; indeed this is at variance with the known fact that, under proper conditions, the saturation state may be approached and passed without any break in continuity. The critical isotherm alone should have an infinite derivative at the critical pressure.

At the lower temperatures, as already noted, a simple quadratic equation having a finite derivative at all points will represent the compressibility measurements with precision and extrapolate to a saturation volume in close agreement with that given by the more complicated equation. It is probable that, even at the higher temperatures, a form of equation might be found which would give a satisfactory representation of the data and have a finite derivative at the saturation pressure.

11. DERIVED THERMAL PROPERTIES OF LIQUID WATER.

The measurements of the total heat of saturated water, made by Osborne, Stimson and Fiock¹³ at the Bureau of Standards, may serve as a convenient starting point for the derivation of certain other interesting thermal properties.

Thus, the constant pressure specific heat at saturation may be calculated from the following thermodynamic relationship:

¹³ Osborne, Stimson and Fiock, Trans. Am. Soc. Mech. Eng., 52, 221 (1930).

$$C_p = \left(\frac{dH}{dT} \right)_{sat.} - \left[v - T \left(\frac{\partial v}{\partial T} \right)_p \right] \left(\frac{dp}{dT} \right)_{sat.} \quad (8)$$

The derivative $\left(\frac{dH}{dT} \right)_{sat.}$ was calculated from the tabulated values of H of Osborne, Stimson and Fiock by the method of Rutledge.¹² Values of v_s and $\left(\frac{\partial v}{\partial T} \right)_p$ resulting from the M. I. T. liquid volume investigation and values of $\left(\frac{dp}{dT} \right)_{sat.}$ from the M. I. T. vapor pressure work¹⁴ were used. Units of cc. atmospheres per gram per degree centigrade were converted to international Joules by multiplying by the factor 0.1012926.¹⁵

The constant volume specific heat, at saturation, was next calculated from the thermodynamic equation:

$$C_v = C_p + T \left(\frac{\partial v}{\partial T} \right)_p^2 \left(\frac{\partial p}{\partial v} \right)_T \quad (9)$$

The results of these two calculations are presented in Table VIII.

The specific heat at constant pressure for compressed liquid water was computed for a few points from the thermodynamic relationship:

$$C_p = C_{p_{sat.}} + T \int_{p_s}^p \left(\frac{\partial^2 v}{\partial T^2} \right)_p dp \quad (10)$$

Required values of the second derivative were obtained by the method of Rutledge. A linear form of equation was found to give a sufficiently exact representation of the second derivative at any temperature as a function of pressure. Thus the second term of equation (10) could be integrated between limits as follows:

$$T \int_{p_s}^p (a + bp) dp = T \left[a(p - p_s) + b/2(p^2 - p_s^2) \right]$$

Values of C_p at 100 atmospheres and 50, 100 and 200° C. are given in Table IX.

The total heat of compressed liquid water may be calculated from the expression:

¹⁴ Smith, Keyes and Gerry, Proc. Am. Acad. Arts and Sci., 69, 137 (1934).

¹⁵ Int. Crit. Tables, Vol. I, p. 24 (1926). 1 cc. atm. = .101325 Joules (abs.)
1 Joule (int.) = 1.00032 Joules (abs.).

$$H = H_{sat.} + \int_{p_s}^p v \, dp - T \int_{p_s}^p \left(\frac{\partial v}{\partial T} \right)_p \, dp \tag{11}$$

For purposes of integration, both the volume and the derivative $\left(\frac{\partial v}{\partial T} \right)_p$ were expressed as linear functions of pressure.

Values of H were thus computed for 100 atmospheres at 50, 100 and 200° C. and are given in Table IX. Other quantities of interest may be easily computed.

TABLE I.
COMPARISON OF "OBSERVED" WITH CALCULATED SATURATION VOLUMES.

<i>t</i>	<i>V_s</i> "Obs." (Series III)	<i>V_s</i> Calc.	Difference Obs.-Calc.
30	1.004445	1.004531	-.000086
50	1.012116	1.012097	+.000019
75	1.025810	1.025704	+.000106
100	1.043437	1.043378	+.000059
150	1.090505	1.090589	-.000084
200	1.156329	1.156516	-.000187
250	1.251487	1.251234	+.000253
300	1.403733	1.403569	+.000164
320	1.498757	1.499236	-.000479
330	1.561779	1.561898	-.000119
340	1.641273	1.640848	+.000425
350	1.745006	1.746777	-.001771
360	1.906541	1.906617	-.000076

TABLE II.
SERIES I.—NICKEL CONTAINER.

30° C.			50° C.		
<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>	<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>
24.212	1.00328	1.003443	24.221	1.01102	1.010994
54.505	1.00191	1.002095	54.514	1.00966	1.009621
84.797	1.00056	1.000763	84.806	1.00831	1.008267
115.089	.99922	.999447	115.099	1.00698	1.006927
145.381	.99788	.998149	145.391	1.00565	1.005605
175.674	.99656	.996846	175.684	1.00434	1.004297
205.966	.99525	.995596	205.976	1.00308	1.003005
236.259	.99395	.994342	236.269	1.00175	1.001728
266.551	.99266	.993105	266.561	1.00047	1.000466
296.844	.99138	.991881	296.854	.99921	.999218
327.137	.99011	.990672	327.147	.99795	.997984
Av. dev. = .03285%			Av. dev. = .00356%		

TABLE II.

SERIES I.—NICKEL CONTAINER.—continued.

75° C.			150° C.		
$P_{atm.}$	$V_{obs.}$	$V_{calc.}$	$P_{atm.}$	$V_{obs.}$	$V_{calc.}$
24.237	1.02466	1.024566	24.309	1.08851	1.089268
54.530	1.02317	1.023116	54.602	1.08646	1.087255
84.822	1.02179	1.021691	84.893	1.08443	1.085273
115.115	1.02038	1.020284	115.185	1.08244	1.083321
145.407	1.01899	1.018893	145.476	1.08048	1.081398
175.700	1.01761	1.017519	175.769	1.07855	1.079504
205.992	1.01625	1.016162	206.060	1.07666	1.077639
236.284	1.01491	1.014821	236.353	1.07480	1.075801
266.576	1.01359	1.013495	266.644	1.07297	1.073989
296.869	1.01228	1.012185	296.937	1.07117	1.072203
327.162	1.01099	1.010889	327.229	1.06941	1.070445
Av. dev. = .00903%			Av. dev. = .08624%		
100° C.			250° C.		
24.257	1.04221	1.042167	54.468	1.24792	1.248421
54.550	1.04064	1.040606	84.757	1.24296	1.243054
84.842	1.03909	1.039064	115.047	1.23780	1.237905
115.135	1.03757	1.037543	145.336	1.23282	1.232958
145.427	1.03607	1.036039	175.626	1.22804	1.228200
175.720	1.03459	1.034554	205.915	1.22343	1.223618
206.011	1.03312	1.033088	236.205	1.21898	1.219202
236.304	1.03168	1.031639	266.497	1.21472	1.214943
266.596	1.03025	1.030209	296.795	1.21062	1.210834
296.889	1.02884	1.028794	327.094	1.20668	1.206862
327.182	1.02743	1.027351	Av. dev. = .01652%		
Av. dev. = .00385%			275° C.		
24.281	1.06304	1.063666	84.811	1.30936	1.309669
54.574	1.06129	1.061922	115.099	1.30168	1.301997
84.866	1.05955	1.060201	145.387	1.29445	1.294767
115.159	1.05784	1.058504	175.676	1.28766	1.287933
145.451	1.05615	1.056831	205.964	1.28123	1.281457
175.744	1.05449	1.055179	236.253	1.27512	1.275309
206.035	1.05284	1.053548	266.541	1.26928	1.269463
236.327	1.05121	1.051939	296.832	1.26373	1.263895
266.619	1.04960	1.050352	327.124	1.25840	1.258584
296.911	1.04802	1.048784	Av. dev. = .01870%		
327.203	1.04645	1.047219			
Av. dev. = .06609%					

TABLE II.

SERIES I.—NICKEL CONTAINER.—continued.

300° C.			300° C.		
$P_{atm.}$	$V_{obs.}$	$V_{calc.}$	$P_{atm.}$	$V_{obs.}$	$V_{calc.}$
84.877	1.39790	1.403482	236.309	1.34310	1.347819
115.163	1.38482	1.390045	266.596	1.33443	1.339148
145.449	1.37308	1.378115	296.886	1.32630	1.331046
175.736	1.36232	1.367199	327.175	1.31864	1.323454
206.022	1.35237	1.357138	Av. dev. = .3647%		

$$\text{Av. dev. all points except } 300^{\circ} \text{ C.} = .03002\% = \frac{1}{3331}$$

$$\text{Av. dev. all points} = .06206\% = \frac{1}{1611}$$

TABLE II.

SERIES II.—CHROME-VANADIUM CONTAINER.

150° C.			250° C.		
$P_{atm.}$	$V_{obs.}$	$V_{calc.}$	$P_{atm.}$	$V_{obs.}$	$V_{calc.}$
24.192	1.08887	1.089276	54.640	1.24854	1.248390
54.486	1.08686	1.087262	84.929	1.24320	1.243023
84.777	1.08487	1.085279	115.218	1.23806	1.237877
115.068	1.08290	1.083329	145.508	1.23310	1.232931
145.360	1.08098	1.081405	175.798	1.22837	1.228174
175.654	1.07907	1.079511	206.088	1.22381	1.223594
205.944	1.07715	1.077646	236.378	1.21938	1.219178
236.237	1.07539	1.075807	266.668	1.21521	1.214920
266.529	1.07357	1.073996	296.959	1.21123	1.210810
296.822	1.07176	1.072211	327.250	1.20722	1.206842
327.115	1.07001	1.070451	Av. dev. = .01946%		

$$\text{Av. dev.} = .03996\%$$

200° C.			300° C.		
$P_{atm.}$	$V_{obs.}$	$V_{calc.}$	$P_{atm.}$	$V_{obs.}$	$V_{calc.}$
24.261	1.15535	1.155610	115.044	1.39085	1.390094
54.552	1.15231	1.152585	115.335	1.39068	1.389974
84.843	1.14934	1.149632	145.619	1.37884	1.378051
115.135	1.14635	1.146744	175.907	1.36803	1.367139
145.425	1.14355	1.143919	206.193	1.35797	1.357084
175.717	1.14079	1.141156	236.431	1.34864	1.347782
206.008	1.13809	1.138449	266.767	1.33992	1.339100
236.300	1.13542	1.135803	297.056	1.33178	1.331002
266.591	1.13279	1.133210	327.345	1.32406	1.323412
296.882	1.13027	1.130672	Av. dev. = .05830%		
327.175	1.12780	1.128185			

$$\text{Av. dev.} = .03114\%$$

TABLE II.

SERIES II.—CHROME-VANADIUM CONTAINER.—continued.

310° C.			340° C.		
$P_{atm.}$	$V_{obs.}$	$V_{calc.}$	$P_{atm.}$	$V_{obs.}$	$V_{calc.}$
115.075	1.43768	1.436992	145.479	1.63524	1.636936
145.358	1.42227	1.421516	175.752	1.59284	1.593427
175.653	1.40853	1.407685	206.028	1.56059	1.561246
205.931	1.39600	1.395176	236.308	1.53437	1.534845
236.215	1.38463	1.383752	266.589	1.51206	1.512366
266.502	1.37413	1.373250	296.872	1.49265	1.492719
296.790	1.36432	1.363539	327.157	1.47549	1.475197
Av. dev. = .05777%			Av. dev. = .03687%		
320° C.			350° C.		
115.110	1.49583	1.495740	166.730	1.72989	1.731739
145.391	1.47465	1.474191	175.808	1.70729	1.708362
175.674	1.45640	1.455888	206.075	1.65088	1.652926
205.958	1.44035	1.439758	236.349	1.61043	1.612875
236.243	1.42606	1.425325	266.626	1.57851	1.581161
266.528	1.41297	1.412269	296.906	1.55213	1.554731
296.815	1.40105	1.400346	327.188	1.52952	1.531898
327.102	1.39001	1.389376	Av. dev. = .1338%		
Av. dev. = .03879%					
330° C.			360° C.		
130.292	1.55666	1.557121	184.972	1.88835	1.893969
145.430	1.54148	1.541450	206.138	1.79242	1.792280
175.709	1.51549	1.515441	236.400	1.71631	1.715496
205.990	1.49356	1.493565	266.670	1.66534	1.664648
236.273	1.47474	1.474594	296.945	1.62684	1.626542
266.557	1.45810	1.457815	327.224	1.59549	1.595783
296.842	1.44312	1.442758	Av. dev. = .07187%		
327.128	1.42956	1.429077			
Av. dev. = .01541%					
			1		
Av. dev. all points except 350° C. = .03933%			= $\frac{1}{2543}$		
			1		
Av. dev. all points			= .04720% = $\frac{1}{2119}$		

TABLE II.

SERIES III.—STAINLESS-STEEL CONTAINER.

30° C.			100° C.		
<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>	<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>
4.223	1.004290	1.004342	4.264	1.043277	1.043207
22.110	1.003386	1.003538	22.153	1.042368	1.042276
46.430	1.002307	1.002452	46.475	1.041014	1.041018
76.244	1.000969	1.001137	76.289	1.039628	1.039496
106.059	.999653	.999839	106.103	1.038083	1.037993
135.872	.998340	.998555	135.916	1.036644	1.036508
165.686	.997054	.997286	165.730	1.035172	1.035042
195.498	.995779	.996033	225.357	1.032342	1.032160
225.311	.994524	.994793	284.985	1.029559	1.029346
255.124	.993270	.993570	344.612	1.026845	1.026600
284.937	.992042	.992360	Av. dev. = .0125%		
314.751	.990825	.991164			
Av. dev. = .02191%					
50° C.			150° C.		
4.216	1.011939	1.011910	6.976	1.090412	1.090434
22.104	1.011097	1.011090	22.233	1.089242	1.089407
46.424	1.009983	1.009987	46.551	1.087581	1.087786
76.238	1.008683	1.008648	76.363	1.085581	1.085828
106.053	1.007376	1.007326	106.175	1.083646	1.083898
135.866	1.006094	1.006019	135.986	1.081840	1.081997
165.681	1.004815	1.004727	165.799	1.079866	1.080124
195.493	1.003531	1.003450	225.423	1.076188	1.076461
225.306	1.002266	1.002188	285.048	1.072609	1.072902
255.121	1.001046	1.000940	344.673	1.069134	1.069443
284.934	.999826	.999707	Av. dev. = .0202%		
314.749	.998605	.998488			
344.562	.997405	.997282			
Av. dev. = .0070%					
75° C.			200° C.		
4.251	1.025614	1.025517	16.353	1.156232	1.156412
22.138	1.024753	1.024657	46.633	1.153154	1.153370
46.457	1.023583	1.023498	76.444	1.150201	1.150444
76.271	1.022238	1.022092	106.257	1.147355	1.147584
106.085	1.020889	1.020702	136.069	1.144524	1.144786
135.899	1.019540	1.019328	165.882	1.141726	1.142046
165.711	1.018210	1.017971	225.506	1.136389	1.136740
225.337	1.015580	1.015303	285.131	1.131302	1.131650
284.964	1.013005	1.012698	344.756	1.126380	1.126763
344.590	1.010489	1.010151	Av. dev. = .0247%		
Av. dev. = .0195%					

TABLE II.

SERIES III.—STAINLESS-STEEL CONTAINER.—continued.

<i>250° C.</i>			<i>330° C.</i>		
<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>	<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>
39.357	1.251461	1.251211	130.032	1.557183	1.557427
46.491	1.250161	1.249878	135.990	1.550498	1.550853
76.301	1.244809	1.244530	165.785	1.523172	1.523421
106.112	1.239711	1.239401	195.582	1.500477	1.500710
135.922	1.234760	1.234476	225.381	1.481033	1.481134
165.733	1.230011	1.229735	284.983	1.448573	1.448474
225.354	1.221066	1.220766	344.590	1.421982	1.421710
284.978	1.212725	1.212420	Av. dev. = .0147%		
344.601	1.204842	1.204630			
Av. dev. = .0225%					
<i>300° C.</i>			<i>340° C.</i>		
86.379	1.403000	1.402695	145.959	1.635917	1.635950
106.281	1.394367	1.393791	165.836	1.605076	1.605805
136.085	1.382344	1.381712	195.625	1.570580	1.571517
165.891	1.371323	1.370678	225.418	1.542905	1.543815
225.506	1.351787	1.351103	255.214	1.519647	1.520430
285.111	1.334707	1.334174	285.012	1.499584	1.500127
344.738	1.319581	1.319306	314.813	1.481861	1.482117
Av. dev. = .0382%			344.612	1.466017	1.465868
			Av. dev. = .0352%		
<i>320° C.</i>			<i>350° C.</i>		
112.706	1.497505	1.497790	168.536	1.725271	1.726497
135.935	1.480671	1.480471	195.684	1.667748	1.669594
165.735	1.461903	1.461626	225.469	1.623526	1.626079
195.537	1.445390	1.445096	255.259	1.589464	1.592325
225.340	1.430735	1.430347	285.051	1.561630	1.564577
284.949	1.405120	1.404895	314.848	1.538020	1.540844
344.562	1.383684	1.383426	344.646	1.517458	1.519951
Av. dev. = .0191%			Av. dev. = .1505%		

TABLE II.

SERIES III.—STAINLESS-STEEL CONTAINER.—continued.

<i>360° C.</i>		
<i>P_{atm.}</i>	<i>V_{obs.}</i>	<i>V_{calc.}</i>
189.539	1.861906	1.861565
195.489	1.833087	1.832380
195.796	1.831580	1.831050
225.559	1.739484	1.738823
255.340	1.682241	1.681748
285.127	1.640401	1.640329
314.920	1.607081	1.607606
344.715	1.579327	1.580244
Av. dev. =		.0310%

<i>370° C.</i>		
213.493	2.075006	2.065802
225.367	1.956446	1.929102
237.263	1.889457	1.849800
249.162	1.841807	1.795978
261.070	1.804528	1.756528
Av. dev. =		1.858%

<i>374° C.</i>	
219.566	2.37955
225.452	2.15945
237.318	2.01260
249.208	1.93430
261.108	1.87990
273.012	1.83798
278.966	1.81737

$$\text{Av. dev. all points except } 350^\circ \text{ and } 370^\circ = .02123\% = \frac{1}{4710}$$

$$\text{Av. dev. including } 350^\circ = .02897\% = \frac{1}{3452}$$

TABLE III.
COMPARISON OF M. I. T. LIQUID VOLUME MEASUREMENTS
WITH THOSE OF AMAGAT.

30° C.			
p	Amagat Specific	M. I. T. "Observed"	Difference %
1	1.00438	1.00441	+ .003
50	1.00202	1.00213	+ .011
100	0.99981	0.99990	+ .009
150	0.99764	0.99771	+ .007
200	0.99549	0.99555	+ .006
250	0.99338	0.99342	+ .004
300	0.99128	0.99134	+ .006
350	0.98922	0.98932	+ .010
50° C.			
1	1.01199	1.01208	+ .009
50	1.00971	1.00984	+ .013
100	1.00749	1.00764	+ .015
150	1.00534	1.00546	+ .012
200	1.00321	1.00333	+ .012
250	1.00111	1.00121	+ .010
300	0.99904	0.99915	+ .011
350	0.99702	0.99712	+ .010
100° C.			
1	1.04317	1.04343	+ .025
50	1.04068	1.04088	+ .019
100	1.03818	1.03836	+ .017
150	1.03573	1.03589	+ .015
200	1.03331	1.03348	+ .016
250	1.03093	1.03111	+ .017
300	1.02857	1.02879	+ .021
350	1.02625	1.02650	+ .024

TABLE IV.

COMPARISON OF M. I. T. SATURATION VOLUMES ABOVE 100° C. WITH
RESULTS OF OTHER OBSERVERS.

Temp.	Volume cc./gram.			
	M. I. T.	Ramsey and Young	Hirn	Waterston
100	1.04338	1.0432	1.04315	
110	1.05154	1.0510		
120	1.06032	1.0594	1.05992	
130	1.06974	1.0678		
140	1.07982	1.0791	1.07949	
150	1.09059	1.0880		
160	1.10209	1.0996	1.10149	
170	1.11436	1.1124		
180	1.12747	1.1260	1.12678	
190	1.14150	1.1412		
200	1.15652	1.1567	1.15900	
210	1.17264	1.1734		1.1800
220	1.19000	1.1915		1.1978
230	1.20875	1.2122		1.2171
240	1.22908	1.2319		1.2385
250	1.25123	1.2516		1.2645
260	1.27551	1.2750		1.2912
270	1.30229	1.3000		1.3204
280	1.33208			1.3518
290	1.36553			1.3856
300	1.40357			1.4280
310	1.44749			1.4742
320	1.49924			1.5363

TABLE V.
CALCULATED SPECIFIC VOLUMES OF LIQUID WATER.

cc. per gram.							
T° C	v_s	1 atm.	25 atm.	50 atm.	75 atm.	100 atm.	125 atm.
0	1.000229	1.000183	0.999084	0.997952	0.996833	0.995724	0.994629
10	1.000564	1.000521	0.999434	0.998315	0.997207	0.996112	0.995028
20	1.002045	1.002001	1.000921	0.999808	0.998707	0.997617	0.996538
30	1.004531	1.004488	1.003407	1.002294	1.001192	1.000101	0.999020
40	1.007910	1.007868	1.006782	1.005661	1.004553	1.003455	1.002367
50	1.012097	1.012057	1.010959	1.009825	1.008703	1.007593	1.006493
60	1.017024	1.016986	1.015871	1.014719	1.013579	1.012450	1.011332
70	1.022645	1.022612	1.021472	1.020297	1.019132	1.017979	1.016838
80	1.028925	1.028899	1.027729	1.026522	1.025328	1.024146	1.022975
90	1.035841	1.035825	1.034619	1.033374	1.032144	1.030924	1.029718
100	1.043378	1.043378	1.042128	1.040839	1.039564	1.038301	1.037051
110	1.051536		1.050256	1.048913	1.047585	1.046271	1.044970
120	1.060319		1.059009	1.057604	1.056215	1.054839	1.053480
130	1.069739		1.068407	1.066932	1.065474	1.064034	1.062609
140	1.079819		1.078462	1.076898	1.075352	1.073824	1.072316
150	1.090589		1.089222	1.087558	1.085917	1.084296	1.082695
160	1.102086		1.100722	1.098939	1.097181	1.095449	1.093737
170	1.114361		1.113024	1.111104	1.109215	1.107350	1.105512
180	1.127474		1.126199	1.124118	1.122071	1.120054	1.118069
190	1.141496		1.140333	1.138061	1.135829	1.133634	1.131476
200	1.156516		1.155535	1.153037	1.150584	1.148178	1.145817
210	1.172641		1.171943	1.169171	1.166459	1.163802	1.161199
220	1.189999		1.189730	1.186626	1.183599	1.180641	1.177751
230	1.208748			1.205603	1.202193	1.198871	1.195636
240	1.229080			1.226359	1.222474	1.218708	1.215050
250	1.251234			1.249235	1.244756	1.240435	1.236259
260	1.275510			1.274692	1.269442	1.264421	1.259592
270	1.302291				1.297092	1.291157	1.285493
280	1.332077				1.328496	1.321333	1.314569
290	1.365532				1.364881	1.355933	1.347665
300	1.403569					1.396485	1.386046
310	1.447490					1.445655	1.431710
320	1.499236						1.488172
330	1.561898						
340	1.640848						
350	1.746777						
360	1.906617						

TABLE V.—continued.

CALCULATED SPECIFIC VOLUMES OF LIQUID WATER.

cc. per gram.						
T°C.	150 atm.	175 atm.	200 atm.	250 atm.	300 atm.	350 atm.
0	0.993545	0.992473	0.991412	0.989324	0.987278	0.985277
10	0.993955	0.992894	0.991844	0.989776	0.987750	0.985764
20	0.995470	0.994413	0.993367	0.991305	0.989286	0.987305
30	0.997951	0.996893	0.995845	0.993779	0.991754	0.989768
40	1.001291	1.000225	0.999169	0.997090	0.995050	0.993048
50	1.005404	1.004326	1.003258	1.001153	0.999089	0.997063
60	1.010226	1.009130	1.008045	1.005905	1.003806	1.001747
70	1.015709	1.014589	1.013481	1.011296	1.009153	1.007051
80	1.021816	1.020667	1.019530	1.017290	1.015093	1.012937
90	1.028522	1.027341	1.026169	1.023862	1.021599	1.019379
100	1.035814	1.034590	1.033377	1.030990	1.028650	1.026355
110	1.043684	1.042410	1.041151	1.038669	1.036239	1.033857
120	1.052135	1.050805	1.049490	1.046898	1.044362	1.041879
130	1.061201	1.059808	1.058430	1.055722	1.053071	1.050478
140	1.070823	1.069350	1.067893	1.065030	1.062233	1.059499
150	1.081113	1.079552	1.078009	1.074981	1.072025	1.069138
160	1.092048	1.090383	1.088737	1.085513	1.082368	1.079302
170	1.103701	1.101914	1.100155	1.096702	1.093345	1.090077
180	1.116116	1.114188	1.112292	1.108581	1.104979	1.101479
190	1.129353	1.127265	1.125211	1.121201	1.117316	1.113551
200	1.143497	1.141220	1.138983	1.134624	1.130413	1.126344
210	1.158649	1.156147	1.153694	1.148929	1.144342	1.139923
220	1.174924	1.172159	1.169453	1.164213	1.159188	1.154366
230	1.192477	1.189398	1.186393	1.180593	1.175058	1.169770
240	1.211495	1.208045	1.204672	1.198210	1.192077	1.186251
250	1.232214	1.228297	1.224499	1.217244	1.210406	1.203949
260	1.254940	1.250456	1.246130	1.237915	1.230236	1.223036
270	1.280073	1.274879	1.269893	1.260503	1.251803	1.243719
280	1.308148	1.302042	1.296223	1.285356	1.275402	1.266242
290	1.339906	1.332594	1.325684	1.312929	1.301395	1.290896
300	1.376417	1.367458	1.359084	1.343839	1.330268	1.318067
310	1.419301	1.407971	1.397534	1.378865	1.362552	1.348083
320	1.471238	1.456270	1.442784	1.419239	1.399151	1.381623
330	1.537173	1.515996	1.497633	1.466748	1.441272	1.419498
340	1.628743	1.594327	1.567110	1.524273	1.490820	1.463088
350		1.710220	1.662437	1.597773	1.552254	1.516435
360			1.814014	1.690528	1.623164	1.575798

TABLE VI.

$$\left(\frac{\partial v}{\partial p}\right)_T \text{ cc. per gram per atmosphere. All derivatives negative.}$$

T°C.	At saturation	1 atm.	25 atm.	50 atm.	75 atm.	100 atm.
0	4.6057×10^{-5}	4.6035×10^{-5}	4.5544×10^{-5}	4.5043×10^{-5}	4.4551×10^{-5}	4.4067×10^{-5}
10	4.5494	4.5472	4.5000	4.4520	4.4048	4.3583
20	4.5232	4.5213	4.4753	4.4288	4.3829	4.3378
30	4.5244	4.5226	4.4775	4.4317	4.3867	4.3424
40	4.5511	4.5492	4.5042	4.4589	4.4142	4.3703
50	4.6016	4.6001	4.5548	4.5093	4.4645	4.4204
60	4.6770	4.6751	4.6289	4.5828	4.5374	4.4928
70	4.7770	4.7752	4.7273	4.6801	4.6336	4.5879
80	4.9029	4.9018	4.8512	4.8023	4.7542	4.7069
90	5.0581	5.0579	5.0025	4.9513	4.9011	4.8516
100	5.2420	5.2420	5.1842	5.1299	5.0769	5.0246
110	5.4616		5.3994	5.3414	5.2846	5.2287
120	5.7200		5.6528	5.5900	5.5285	5.4680
130	6.0070		5.9495	5.8806	5.8132	5.7471
140	6.3790		6.2966	6.2199	6.1453	6.0721
150	6.7895		6.6958	6.6096	6.5258	6.4439
160	7.2830		7.1770	7.0783	6.9829	6.8897
170	7.8530		7.7341	7.6193	7.5092	7.4021
180	8.7270		8.3910	8.2557	8.1268	8.0016
190	9.3240		9.1694	9.0054	8.8523	8.7043
200	1.0277×10^{-4}		1.0099×10^{-4}	9.8975	9.7122	9.5339
210	1.1415		1.1226	1.0964×10^{-4}	1.0736×10^{-4}	1.0515×10^{-4}
220	1.2805		1.2642	1.2252	1.1965	1.1690
230	1.4490			1.3827	1.3457	1.3107
240	1.6607			1.5783	1.5291	1.4846
250	1.922			1.8271	1.7582	1.6990
260	2.258			2.1657	2.0503	1.9692
270	2.700				2.4337	2.3176
280					2.9619	2.7804
290					3.8985	3.4215
300						4.3730
310						6.2343
320						
330						
340						
350						
360						

TABLE VI.—continued.

$\left(\frac{\partial v}{\partial p}\right)_T$ cc. per gram per atmosphere. All derivatives negative.

°C.	125 atm.	150 atm.	175 atm.	200 atm.	250 atm.	300 atm.	350 atm.
0	4.3590×10^{-5}	4.3122×10^{-5}	4.2660×10^{-5}	4.2207×10^{-5}	4.1320×10^{-5}	4.0462×10^{-5}	3.9629×10^{-5}
10	4.3125	4.2675	4.2232	4.1795	4.0942	4.0115	3.9313
20	4.2934	4.2496	4.2065	4.1640	4.0810	4.0005	3.9224
30	4.2988	4.2558	4.2134	4.1717	4.0901	4.0109	3.9339
40	4.3269	4.2843	4.2422	4.2008	4.1198	4.0410	3.9645
50	4.3770	4.3342	4.2920	4.2505	4.1692	4.0902	4.0134
60	4.4488	4.4054	4.3627	4.3206	4.2382	4.1581	4.0803
70	4.5428	4.4985	4.4547	4.4116	4.3273	4.2454	4.1657
80	4.6603	4.6144	4.5692	4.5246	4.4375	4.3528	4.2705
90	4.8029	4.7550	4.7077	4.6612	4.5701	4.4818	4.3959
100	4.9731	4.9224	4.8725	4.8234	4.7273	4.6342	4.5437
110	5.1737	5.1196	5.0664	5.0140	4.9115	4.8123	4.7160
120	5.4086	5.3502	5.2928	5.2362	5.1259	5.0190	4.9154
130	5.6822	5.6184	5.5557	5.4941	5.3738	5.2575	5.1449
140	6.0003	5.9298	5.8605	5.7925	5.6600	5.5320	5.4084
150	6.3636	6.2848	6.2076	6.1317	5.9842	5.8420	5.7047
160	6.7985	6.7093	6.6217	6.5360	6.3694	6.2092	6.0550
170	7.2973	7.1950	7.0948	6.9967	6.8066	6.6243	6.4492
180	7.8797	7.7606	7.6443	7.5306	7.3110	7.1008	6.8997
190	8.5603	8.4201	8.2834	8.1502	7.8932	7.6484	7.4149
200	9.3611	9.1934	9.0303	8.8716	8.5669	8.2778	8.0032
210	1.0304×10^{-4}	1.0100×10^{-4}	9.9025	9.7109	9.3441	8.9980	8.6710
220	1.1429	1.1177	1.0934×10^{-4}	1.0699×10^{-4}	1.0251×10^{-4}	9.8316	9.4376
230	1.2779	1.2465	1.2162	1.1871	1.1320	1.0808×10^{-4}	1.0329×10^{-4}
240	1.4425	1.4024	1.3641	1.3275	1.2586	1.1952	1.1365
250	1.6439	1.5918	1.5424	1.4955	1.4081	1.3284	1.2555
260	1.8953	1.8262	1.7614	1.7002	1.5876	1.4863	1.3949
270	2.2125	2.1196	2.0331	1.9522	1.8053	1.6753	1.5596
280	2.6342	2.5033	2.3838	2.2737	2.0775	1.9078	1.7599
290	3.1806	3.0002	2.8345	2.6836	2.4193	2.1961	2.0057
300	4.0018	3.7120	3.4625	3.2428	2.8717	2.5703	2.3216
310	5.2152	4.7329	4.3435	4.0132	3.4784	3.0640	2.7351
320	7.2993	6.3351	5.6687	5.1372	4.3268	3.7377	3.2934
330		9.1941	7.8446	6.9294	5.5632	4.6819	4.0615
340		1.6527×10^{-3}	1.1246×10^{-3}	9.9244	7.4613	6.0342	5.1210
350			2.3184	1.6179×10^{-3}	1.0541×10^{-3}	7.9467	6.5065
360				3.8165	1.6927	1.0941×10^{-3}	8.3133

TABLE VII.

$$\left(\frac{\partial v}{\partial T}\right)_p \text{ cc. per gram per degree C.}$$

T°C.	At saturation	1 atm.	25 atm.	50 atm.	75 atm.	100 atm.
0	-3.0875×10^{-5}	-3.0803×10^{-5}				
10	$+9.3894 \times 10^{-5}$	$+9.3933 \times 10^{-5}$				
20	2.0024×10^{-4}	2.0026×10^{-4}				
30	2.9500	2.9498	2.9467×10^{-4}	2.9426×10^{-4}	2.9394×10^{-4}	2.9352×10^{-4}
40	3.7975	3.7971	3.7888	3.7779	3.7678	3.7584
50	4.5685	4.5681	4.5537	4.5382	4.5223	4.5068
60	5.2843	5.2838	5.2628	5.2428	5.2214	5.1998
70	5.9623	5.9614	5.9336	5.9062	5.8793	5.8531
80	6.6105	6.6092	6.5767	6.5411	6.5093	6.4758
90	7.2412	7.2407	7.2006	7.1602	7.1196	7.0790
100	7.8650	7.8650	7.8173	7.7692	7.7201	7.6741
110	8.4935		8.4379	8.3793	8.3220	8.2642
120	9.1335		9.0734	9.0090	8.9455	8.8844
130	9.7940		9.7214	9.6420	9.5630	9.4872
140	1.0485×10^{-3}		1.0400×10^{-3}	1.0306×10^{-3}	1.0214×10^{-3}	1.0122×10^{-3}
150	1.1214		1.1123	1.1014	1.0909	1.0809
160	1.1998		1.1890	1.1762	1.1638	1.1515
170	1.2835		1.2726	1.2578	1.2435	1.2293
180	1.3746		1.3639	1.3463	1.3292	1.3129
190	1.4754		1.4648	1.4441	1.4238	1.4045
200	1.5876		1.5779	1.5531	1.5293	1.5063
210	1.7141		1.7066	1.6765	1.6480	1.6206
220	1.8576		1.8543	1.8179	1.7832	1.7502
230	2.0215			1.9818	1.9392	1.8992
240	2.2123			2.1751	2.1222	2.0728
250	2.439			2.4080	2.3404	2.2785
260	2.707			2.6931	2.6056	2.5263
270					2.9359	2.8317
280					3.365	3.2179
290					3.939	3.723
300						4.432
310						5.465
320						
330						
340						
350						

TABLE VII.—continued.

$$\left(\frac{\partial v}{\partial T}\right)_p \text{ cc. per gram per degree C.}$$

125 atm.	150 atm.	175 atm.	200 atm.	250 atm.	300 atm.	350 atm.
2.9305×10^{-4}	2.9266×10^{-4}	2.9216×10^{-4}	2.9163×10^{-4}	2.9085×10^{-4}	2.8978×10^{-4}	2.8868×10^{-4}
3.7491	3.7389	3.7287	3.7186	3.6991	3.6799	3.6597
4.4918	4.4768	4.4620	4.4477	4.4169	4.3874	4.3591
5.1793	5.1596	5.1385	5.1186	5.0787	5.0391	5.0013
5.8266	5.8002	5.7734	5.7474	5.6976	5.6488	5.6003
6.4434	6.4097	6.3797	6.3477	6.2869	6.2270	6.1680
7.0397	7.0008	6.9636	6.9255	6.8523	6.7808	6.7115
7.6262	7.5821	7.5348	7.4919	7.4048	7.3221	7.2415
8.2096	8.1545	8.1014	8.0504	7.9459	7.8468	7.7518
8.8237	8.7645	8.7065	8.6478	8.5382	8.4298	8.3267
9.4126	9.3384	9.2668	9.1956	9.0602	8.9299	8.8044
1.0034×10^{-3}	9.9465	9.8621	9.7796	9.6178	9.4647	9.3166
1.0708	1.0611×10^{-3}	1.0517×10^{-3}	1.0422×10^{-3}	1.0245×10^{-3}	1.0073×10^{-3}	9.9082
1.1397	1.1282	1.1169	1.1062	1.0848	1.0647	1.0457×10^{-3}
1.2157	1.2027	1.1895	1.1771	1.1529	1.1302	1.1086
1.2969	1.2814	1.2664	1.2517	1.2240	1.1977	1.1729
1.3858	1.3675	1.3502	1.3332	1.3010	1.2706	1.2423
1.4842	1.4630	1.4424	1.4225	1.3849	1.3499	1.3174
1.5943	1.5691	1.5448	1.5215	1.4777	1.4372	1.3996
1.7189	1.6886	1.6599	1.6325	1.5811	1.5339	1.4906
1.8611	1.8250	1.7912	1.7579	1.6972	1.6421	1.5921
2.0262	1.9823	1.9408	1.9014	1.8292	1.7645	1.7064
2.2207	2.1664	2.1151	2.0680	1.9811	1.9044	1.8361
2.4529	2.3852	2.3222	2.2633	2.1577	2.0654	1.9847
2.7368	2.6498	2.5699	2.4963	2.3654	2.2528	2.1558
3.0910	2.9766	2.8727	2.7781	2.6124	2.4725	2.3532
3.5466	3.3910	3.2520	3.1271	2.9125	2.7348	2.5853
4.1563	3.9339	3.7399	3.5687	3.2800	3.0459	2.8510
5.035	4.6775	4.3925	4.1471	3.7448	3.4266	3.1654
6.341	5.7554	5.3111	4.9397	4.3553	3.9101	3.5525
	7.626	6.6851	6.0809	5.1780	4.5304	4.0281
	1.099×10^{-2}	9.297	7.8934	6.4743	5.5320	4.8443
		1.439×10^{-2}	1.168×10^{-2}	8.280	6.715	5.763

TABLE VIII.

T°C.	$H_{sat} O. S. \& F.$	$\frac{dH}{dT_{sat.}}$	C_p at sat.	C_v at sat.
0	0.	(4.2208)	(4.2208)	(4.2202)
10	42.02	(4.1878)	(4.1877)	(4.1821)
20	83.83	4.1773	4.1772	4.1509
30	125.59	4.1749	4.1747	4.1156
40	167.34	4.1766	4.1763	4.0758
50	209.11	4.1770	4.1765	4.0280
60	250.90	4.1816	4.1808	3.9793
70	292.75	4.1880	4.1869	3.9282
80	334.66	4.1945	4.1930	3.8742
90	376.65	4.2043	4.2022	3.8208
100	418.75	4.2154	4.2127	3.7666
110	460.97	4.2299	4.2264	3.7137
120	503.36	4.2479	4.2435	3.6627
130	545.93	4.2666	4.2611	3.6090
140	588.71	4.2905	4.2839	3.5626
150	631.75	4.3178	4.3099	3.5160
160	675.06	4.3432	4.3340	3.4679
170	718.66	4.3823	4.3719	3.4302
180	762.72	4.4253	4.4137	3.4198
190	807.15	4.4640	4.4514	3.3561
200	852.02	4.5090	4.4958	3.3203
210	897.35	4.5596	4.5465	3.2868
220	943.24	4.6188	4.6066	3.2604
230	989.75	4.6853	4.6755	3.2381
240	1036.97	4.7609	4.7560	3.2241
250	1084.97	4.8406	4.8423	3.2018
260	1133.87	4.9523	4.9651	3.2127
270	1184.32	(5.1574)		

TABLE IX.

T°C.	$C_{p_{sat.}}$	$C_{p_{100 atm.}}$	$H_{sat.}$	$H_{100 atm.}$
International Joules.				
50	4.1765	4.2003	209.11	217.84
100	4.2127	4.2354	418.75	426.28
200	4.4958	4.5424	852.02	855.63

(Contribution from the Research Laboratory of Physical Chemistry,
Massachusetts Institute of Technology, No. 327.)

III-A. THE COMPRESSIBILITY OF MERCURY FROM 30° TO 300° C.

BY LEIGHTON B. SMITH AND FREDERICK G. KEYES.

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In a recent paper describing the apparatus and procedures employed in the Massachusetts Institute of Technology steam research program Keyes¹ has shown how the dilation with pressure of a nickel steam container was determined from measurements of the apparent compressibility of mercury. For the true compressibility, use was made of the values given by Carnazzi² since they cover a much wider temperature range than the well known measurements of Bridgman³ and of Richards and Stull.⁴ Keyes has shown that the dilation of the container determined in this manner agreed to better than five per cent with that calculated from the elastic constants of the nickel.

Of the observed or apparent compression effect only about one-third was due to the dilation of the container while the remainder or two-thirds was due to the compressibility of the mercury. It is therefore worth while to evaluate the compressibility of mercury from the data at hand, particularly since values might be calculated for temperatures higher than any reported in the literature.

Observations of the apparent compressibility had been made at 30, 100, 150, 200, 250, and 300° C. Above 200°, however, some trouble had been experienced due to amalgamation of the nickel with the mercury, finally resulting in the development of a leak. It is therefore possible that less reliance should be placed on the results at 250° and 300° C.

The dilation with pressure of the essentially cylindrical nickel container was calculated from the formula:

$$\Delta V = V \left[\frac{3(1 - 2\sigma)}{E} \frac{(p_i r_i^2 - p_o r_o^2)}{(r_o^2 - r_i^2)} + \frac{2(1 + \sigma)}{E} \frac{(p_i - p_o) r_o^2}{(r_o^2 - r_i^2)} \right]$$

¹ Keyes, Proc. Am. Acad. Arts and Sci., 68, 516 (1933).

² Carnazzi, Cim. (5) 5, 180 (1903).

³ Bridgman, Proc. Am. Acad. Arts and Sci., 47, 347 (1912).

⁴ Richards and Stull, J. Am. Chem. Soc., 26, 399 (1904).

where ΔV is the volume displacement when the internal pressure is p_i and the outside pressure is p_o , r_i is the internal radius, r_o the external radius, E is Young's modulus and σ Poisson's ratio. Values for the various constants in the equation have been given by Keyes.¹ The end effect was approximated by considering the ends as equivalent hemispheres and was found to be small in comparison with the dilation of the cylindrical portion of the container.

Values of the mean compressibility coefficient, $\frac{1}{V} \frac{\Delta V}{\Delta p}$, from 1 to 350 atmospheres have been calculated for each temperature and are listed in the following table.

MEAN COMPRESSIBILITY COEFFICIENT OF MERCURY.

	$\frac{1}{V} \frac{\Delta V}{\Delta p}$					
$P_{atm.}$	30° C.	100° C.	150° C.	200° C.	250° C.*	300° C.*
1- 50	3.873×10^{-6}	4.259×10^{-6}	4.518×10^{-6}	4.879×10^{-6}	5.551×10^{-6}	6.970×10^{-6}
1-100	3.859	4.231	4.480	4.835	5.461	6.413
1-150	3.850	4.208	4.447	4.798	5.375	6.004
1-200	3.843	4.188	4.417	4.762	5.292	5.757
1-250	3.834	4.165	4.384	4.724	5.206	5.608
1-300	3.823	4.140	4.348	4.683	5.117	5.520
1-350	3.809	4.112	4.311	4.641	5.026	5.422

*Slight amalgamation occurred at these temperatures.

The average temperature coefficient of compressibility between 30° and 200° C. is seen to be about 5.5×10^{-9} .

Richards and Stull⁴ report a value of 3.93×10^{-6} for the mean compressibility coefficient between 0 and 98.7 atmospheres at 20° C. Applying the temperature coefficient 5.5×10^{-9} gives a value of 3.99×10^{-6} at 30° to be compared with the value 3.859×10^{-6} given in the table. Bridgman's results,³ though not easily compared with the present work due to differences in the pressure range covered, are seen to be still higher. Carnazzi² finds 3.8×10^{-6} as the mean coefficient between 1 and 500 atmospheres at 22.8° C. This would be equivalent to approximately 3.9×10^{-6} at 30° C. and for the pressure range from 1 to 100 atmospheres.

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THE MICROBIOLOGY OF THE UPPER AIR. I.

BY BERNARD E. PROCTOR.



THE MICROBIOLOGY OF THE UPPER AIR. I.

By BERNARD E. PROCTOR.

Read April 11, 1934.

Introduced by J. W. M. Bunker.

THE collection of micro-organisms from the air at various altitudes has interested observers for a considerable time. Pasteur, one of the first workers in this field, made investigations by climbing the Alps to obtain his samples. More recently the airplane has made it possible for others to make studies on the micro-organisms found in the upper air which occur in various regions.

Stakman, Henry, Curran, and Christopher found numerous spores in airplane flights in Texas, Minnesota, Nebraska, and Wyoming.¹ Mischustin reported results obtained over the Moscow experimental flying field.² Craigie and Popp have used airplanes in collecting rust spores from the upper air in Canada.³ Brown made collections of living micro-organisms in the air of the arid section in southwestern United States.⁴ Meier, Stevenson and Charles have identified fungus spores collected on flights over eastern United States in 1932.⁵

The establishment in 1931 of a daily airplane flight service by the Division of Meteorology of the Department of Aeronautical Engineering at the Massachusetts Institute of Technology suggested an opportunity to study the microbiology of the upper strata in the vicinity of Boston. The first flight on which studies of a biological nature were undertaken was on February 23, 1932. Through the courtesy and coöperation of the staff of the Division of Meteorology it has been possible to collect a considerable number of biological samples which were immediately taken to the laboratories of the Department of Biology and Public Health for biological examination.

PRELIMINARY EXPERIMENTS.

On the first flight a series of six sterilized Petri plates containing standard nutrient agar was used for the collections at different altitudes. Each of these plates was exposed separately by opening it

¹ Stakman, E. C., Henry, A. W., Curren, G. C., and Christopher, W. N. *Jour. Agri. Research.* **24** (7): 599-606, 2 pls. 1923.

² Mischustin, E. *Centralblatt f. Bakt. etc., II. Abt., Bd. 67*: 347-351. 1926.

³ Craigie, J. H. and Popp, W. *Rust Epidemiology.* Canada, Dept. Agric., Exper. Farms, Report of the Dominion Botanist for 1927: p. 47-54. 1928.

⁴ Brown, J. G. *Science* **72**: 322-323. 1930.

⁵ Meier, F. C., Stevenson, J. A., and Charles, V. K. *Phytopathology* **23**: 23. 1933.

just outside of the cabin. The lower half of the plate was extended at arm's length from the cabin door and exposed to the air for one minute while the plane was operated at an approximate speed of 100 miles per hour. At the end of this time, the cover was replaced and the closed plate returned to the cabin. The plates were immediately returned to the laboratory and incubated for 72 hours at 20° C. Table I contains the data obtained from this flight, together with the temperatures at each exposure altitude.

TABLE I.
MICRO-ORGANISMS OBTAINED ON FLIGHT A.

Petri plate	Altitude ft.	C° Temp.	Mold count	Bacteria count
1	13,300	-35	60	23
2	10,700	-28	10	31
3	7,600	-23.5	15	36
4	5,800	-18	14	20
5	5,700	-18	18	20
6	2,000	-8	50	25

A short time later four more flights were made, each on a separate day, during which collections were taken. The Petri plates were exposed for one minute each at different elevations.

Previous to the day of exposure, all the Petri plates used in these experiments were observed in the laboratory for 2 days to make sure that no contaminating organisms were present. Surgeon's tape was used to seal the upper and lower sections of the plates, between the airport at East Boston and the laboratory, and the plates were further protected during transportation by being placed in a tight, sterile, metal box.

Precautions were also taken to exclude dust contamination in the cabin by opening the plates for exposure only after thrusting them out the door. The results obtained are included in Table II.

TABLE II.
MICRO-ORGANISMS OBTAINED ON FLIGHTS B, C, D AND E.

Altitude in ft.	Flight B		Flight C		Flight D		Flight E	
	Bact.	Molds	Bact.	Molds	Bact.	Molds	Bact.	Molds
1,500	218	300	—	—	16	21	—	—
3,000	179	5	11	0	27	8	137	5
6,000	4	2	33	43	3	5	8	1
9,000	4	0	5	3	1	0	191	1
12,000	12	0	5	0	1	98	14	3
15,000	8	0	4	1	7	0	39	6

The preliminary observations indicated the need of a type of apparatus which would enable micro-organisms to be collected from the upper air with no danger of contamination from other sources. No known device was found to meet the definite limitations of weight, size, wide temperature range, and need for semi-automatic operation which were imposed by the fact that the flights of this plane were primarily concerned with meteorological research and the single occupant served the dual rôle of pilot and observer. In addition it was hoped that examinations could be made simultaneously for the presence of pollen, and possibly for dust, in the air.

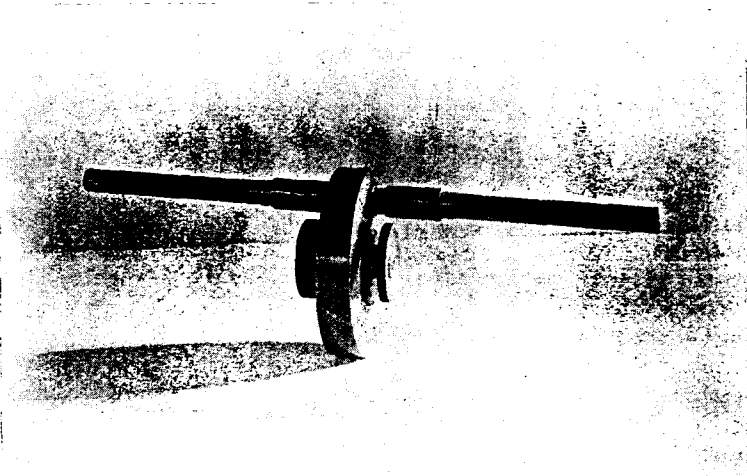


FIGURE 1. Collecting apparatus assembled. Tubes for air inlet and outlet connected.

After numerous tests with a variety of devices, a collecting apparatus was devised which, though not ideal, met most of the limitations mentioned. In essence, this apparatus, Fig. 1, was a cylindrical brass compartment five inches in diameter and less than an inch in depth, within which was a rotating metal plate, Fig. 2. When this plate was rotated, it was possible to expose separate disks of especially treated lens paper in such a manner that an air current drawn through the compartment passed through the interstices of the paper which acted as a filter.

The filter disks were first washed in chloroform, then dried and treated with a highly purified hydrocarbon oil having a congealing

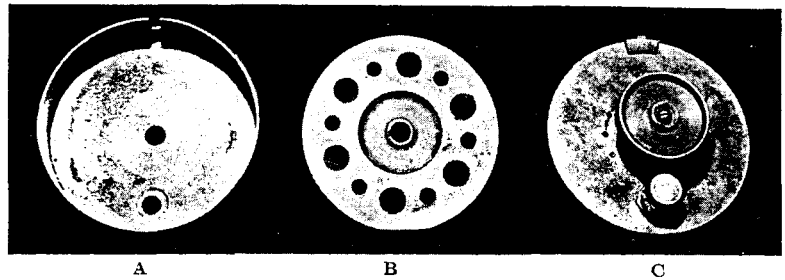


FIGURE 2. Parts of collecting apparatus.

- A. Outer shell, showing air outlet.
- B. Rotating metal plate, with circular wire screens used to hold paper disks.
- C. Front cover. Knob for rotating inner metal plate in the center. Metal cap used to cover air inlet during transportation shown below knob.

point of -71°C. , before being placed in the apparatus. The entire mechanism was then subjected to heat sterilization with steam at a pressure of 20 pounds for 30 minutes in the laboratory. On reaching the airport at East Boston, the inlet and outlet to the compartment were attached to a short line going through the roof of the plane to a Venturi tube, Fig. 3, and to the collector attached in a fixed position in the cabin just above the pilot, Fig. 4. In order to obviate contamination during the process of connecting the apparatus, a free air channel through the collector is maintained by means of a hole drilled through the inner rotating plate which may be kept in line with the air stream until it is desired that the collection start. There are six paper filters for collecting micro-organisms in the apparatus and six free holes between, making it possible to air-wash the entire system after each exposure. A one minute period of air-flow through the free holes was observed as a regular procedure between exposures.

Certain control measures were instituted to insure, so far as possible, that such bacteria as were obtained came from the air at the levels indicated. The results of a flight were rejected if the control disk, always left unexposed, was not found sterile on subsequent examination.

One flight, during which an exposure was made while the plane taxied along the ground, showed that subsequent exposures might be sterile, although one exposure contained many micro-organisms. This tends to indicate that if the air flow through the open hole intervened between exposures, there was but slight possibility of contamination at higher altitudes.

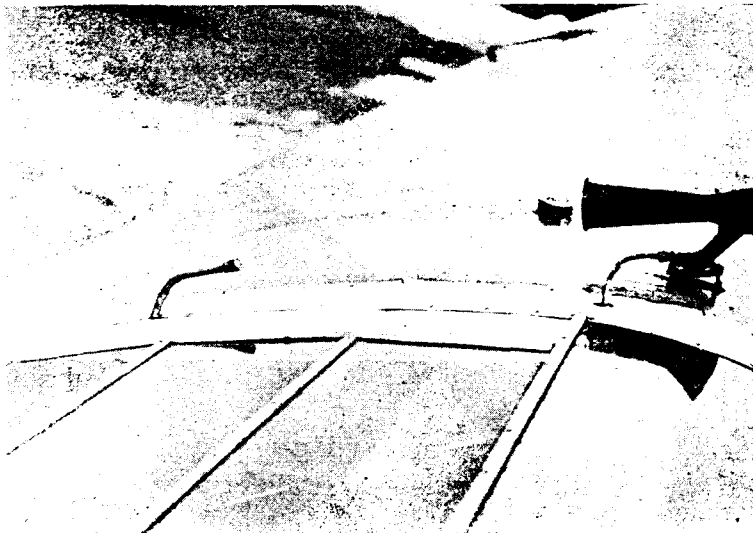


FIGURE 3. Roof of plane, showing Venturi tube at right and air inlet tube on left.

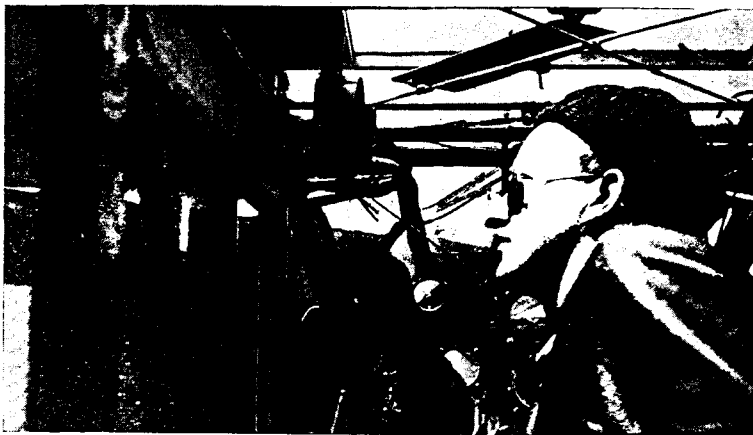


FIGURE 4. Interior of cabin of plane, with collection apparatus installed. (Pilot, Lt. H. B. Harris).

No claim is made that this collecting device arrests all the micro-organisms from the air which passes through it. The use of a water trap in series with it proved definitely that such was not the case. If indeed such a device were a perfect trap, the air flow would be so reduced that it would be questionable whether any organisms would be obtained in a reasonable length of exposure. It is considered, however, that the apparatus has many advantages over Petri dishes as a collecting agent and affords some means of comparison between various exposures.

Tests conducted to determine the approximate air flow through the collecting device were made by the staff of the Division of Meteorology, using the Technology wind-tunnel. These results indicated an air flow through the collector of approximately 1 cubic foot per minute under general flight conditions.

The usual flights were slow, more or less steady ascents in a westerly direction from East Boston until the highest altitude (ceiling) was reached that seemed advisable, then a more rapid descent and return to the airport. This plane, Fig. 5, a Curtiss-Robin equipped with a Challenger 185 H. P. engine, when carrying all its numerous meteorological instruments reaches, under optimum conditions of flight, a height of about 20,000 feet. Such an altitude was not commonly attained in most of the flights under discussion, 17,000 to 18,000 feet being the usual height reached.

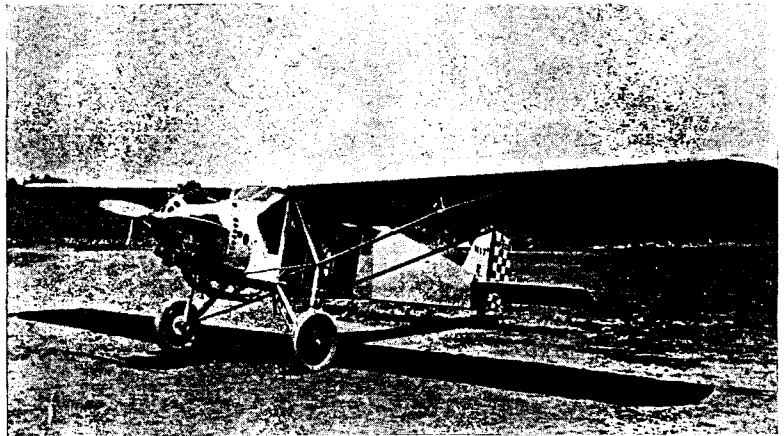


FIGURE 5. Airplane used in making collections, through the coöperation of the Division of Meteorology, Massachusetts Institute of Technology.

LABORATORY PROCEDURE.

The collection apparatus was returned to the laboratory on the completion of each flight. If the following examinations could not be carried out within a few hours, the "collector" was kept in a mechanical refrigerator until the next day.

Using aseptic technique, the oiled paper filters were removed from the collector and placed in a specially sterilized glass cell, covered by a large microscope cover slip. Each paper disk was then examined with a microscope, using a 16 mm. objective and a 10× ocular lens. By means of a mechanical stage it was possible to observe and sketch any pollen grains which were found, and in a number of the flights an examination and count of dust particles was made simultaneously.

On completion of direct microscopic examination, the paper disks were removed from the glass cell with sterile forceps and each placed in a separate tube containing 10 cc. of sterile water. After a period of five minutes' soaking, the tubes, plugged with sterilized rubber stoppers, were shaken thoroughly until the paper disks disintegrated into separate fibers. Then the water in each tube was transferred with sterile pipettes to sterile Petri dishes, using two or three cc. to each plate. Immediately thereafter standard nutrient agar was added in the usual manner, allowed to cool, and the plates incubated at 20° C. for 5 days. At the end of this time they were placed in a 37° C. incubator for 2 days. Counts were made after each incubation period. Under the above conditions no anaerobic organisms would be capable of growth.

BACTERIA.

Table III gives the results obtained from exposures made on 40 flights. No attempt was made to determine the number of organisms according to length of exposure. As the exposures were made over a considerable range of altitude, at each level of which the air masses are likely to vary considerably, a ratio of micro-organisms to time would likely be of little value. It would have been ideal if the exposures could have been made at definite fixed altitudes for certain periods of time. This was possible only in one flight, because the primary purpose of the flights was for meteorological observations, which necessitate different procedure.

As the temperatures at the greatest elevation and at the ground are included, it will be noted that the temperatures are rather low, particularly during the first of this series, which started in January, 1933.

TABLE III.

BACTERIA AND MOLDS AT DIFFERENT ALTITUDES.

Flight No.	Altitude 1000 ft.	Minutes exposed	Bact.	Molds	Temp. °C.
1	1.0-7.0	10	4	9	G. 2.6
	9.-14.0	10	5	0	
	14.4-16.6	10	2	0	
	16.8-17.8-14.2	10	1	2	-21.5
	11.6-.5	10	18	1	
2	15.5-17.5	10	3	2	-26.5
	17.5-11.5	10	1	2	
	9.5-.5	10	28	22	G. 4.5
3	12.5-16.8		0	71	-22.5
	17.0-19.1-18.0		1	73	
	17.8-gr.		18	108	G. 1.0
4	1.0-7.6	10	0	0	-31.5
	9.0-14.0	10	4	1	
	14.4-16.5	10	0	2	
	16.5-17.2-14.0	10	0	0	
	11.5-gr.	10	2	3	G. 2.8
5	1.0-7.5	10	0	0	-22.
	9.0-14.0	10	0	0	
	14.4-16.6	10	1	0	
	16.8-17.7-14.0	10	1	1	
	9.5-gr.	10	3	12	G. - 2.
6	1.4-9.1	12	1	0	-18.
	9.8-13.5	12	0	5	
	14.5-15.2	12	0	0	
	15.4-18.0	12	0	0	
	18.4-gr.	12	18	7	G. - 2.
7	1.0-9.0	12	0	1	-1.5
	9.4-13.4	12	2	0	
	13.6-14.6	12	1	1	
	15.4-17.4	12	0	1	
	18.0-11.4	12	2	2	-28.

TABLE III—cont.

Flight No.	Altitude 1000 ft.	Minutes exposed	Bact.	Molds	Temp. °C.
8	2.0-10.0	12	2	0	
	11.0-14.0	12	0	0	
	14.5-16.8	12	0	1	
	17.0-18.2	12	0	0	-22.
	16.0-gr.	12	9	11	G. 0
9	3.0-9.5	12	0	0	
	10.5-13.5	12	1	2	
	13.8-15.4	12	1	0	
	17.2-18.2	12	0	0	-33.
	13.5-gr.	12	0	1	G. 3
10	3.0-9.5	12	1	0	
	10.5-13.5	12	0	0	
	13.8-15.4	12	1	0	
	16.0-17.2	12	0	0	-30.
	12.5-gr.	12	9	2	G. -12.
11	2.0-9.0	12	3	1	G. - 2.
	10.0-15.8	20	3	9	
	16.4-17.6	12	1	0	-17.
12	7.0-11.2		2	1	G. 13
	12.4-14.2		2	0	
	14.4-15.5		0	0	
	16.0-17.0-5.0		0	0	-13
	4.2-2.6		0	11	
13	7.4-16.2	20	0	0	
	16.4-18.8-10.0	20	3	0	-22.
	9.0-gr.	20	18	0	G. -12
14	3.0-14.6	23	0	0	
	14.8-17.5	20	0	0	
	17.6-18.8	20	0	0	-32
	17.5-gr.	20	28	0	G. - 6
15	gr. -11.2	17	0	0	
	11.4-16.1	17	0	0	
	16.2-17.2	17	0	0	
	17.2-17.4-5.0	17	0	0	-27
	5.0-gr.	6	10	43	G. 2

TABLE III—cont.

Flight No.	Altitude 1000 ft.	Minutes exposed	Bact.	Molds	Temp. °C.
16	gr. -10.0	15	1	1	
	10.6-14.8	10	0	0	-39
	14.4-gr.	20	0	0	G. 4
17	1.0-9.2	15	1	1	
	11.3-15.0	15	0	0	G. 9
	15.4-16.2	15	0	0	
	16.2-16.4-1.0	15	0	1	-30
18	5.0-10.7	15	0	0	
	11.0-13.4	15	2	1	
	13.6-18.0	15	1	0	
	18.2-18.8	15	0	0	-34
	17.0-gr.	15	2	0	G. - 4
19	.5-9.0	20	2	0	G. 1
	9.4-12.8	20	0	0	
	13.4-17.0	20	0	0	
	17.5-18.6	20	0	0	-32
	18.2-.5	20	3	0	
20	1.2-10.6	15	2	1	G. 0
	10.8-14.5	15	1	0	
	14.7-16.9	15	0	0	
	17.2-18.0-7.5	15	0	0	-29
21	1.0-12.0	15	0	0	G. -11
	12.2-16.0	19	0	0	
	16.0-17.2	15	6	0(1Y)	
	17.2-19.6	15	0	0	
	19.6-20.6	15	4	2	-36
22	12.8-16.0	17	0	0	
	17.5-18.8	17	0	0	-27
	17.8-gr.	17	11	0	G. - 4
23	1.0-10.6	15	0	0	G. 3
	10.8-15.4	15	1	0	
	15.8-17.8	15	0	0	
	18.0-18.4-11.6	15	0	0	-23
	11.4-5.0	15	1	1	

TABLE III—cont.

Flight No.	Altitude 1000 ft.	Minutes exposed	Bact.	Molds	Temp. °C.
24	gr. -10.0	15	4	0	
	11.4-14.8	15	0	0	
	14.9-16.4	15	0	0	
	16.6-18.2	15	0	0	-25
	18.2-gr.	15	0	0	G. 4
25	1.0-10.6	15	0	0	
	11.0-15.2	15	0	0	
	15.4-18.0	15	1	0	
	18.2-19.4-15.0	15	0	0	-38
	13.0-gr.	15	5	0	G. 3
26	2.0-11.0	20	0	0	G. 5
	11.8-17.0	20	0	0	
	17.2-19.4	20	1	0	-31
27	1.5-8.6	20	8	0	
	7.2-13.0	20	0	0	G. 9
	13.4-15.4	20	4	0	
	15.6-17.4	20	6	0	-10
	17.5-16.5	20	3	3	
28	1.0-10.0	20	0	1	
	11.2-15.4	20	1	0	G. 13
	15.7-18.4	20	0	0	
	18.5-19.8	20	0	0	-17
	19.8-.4	20	0	0	
29	1.0-10.0	15	0	0	G. 9
	11.5-16.5	18	0	0	
	16.8-18.3	15	4	0	
	18.4-19.6	15	0	0	-20
	19.6-1.0	15	0	0	
30	8.5-12.5	12	0	0	
	13.0-14.8	12	1	0	G. 2
	15.0-16.4	12	0	0	
	17.0-14.0	12	3	1	-25
31	.5-9.4	17	12	10	
	9.7-14.4	17	2	0	G. 14
	14.8-15.0	17	4	1	
	18.0-.5	17	13	13	-21

TABLE III—cont.

Flight No.	Altitude 1000 ft. .	Minutes exposed	Bact.	Molds	Temp. °C.
32	1.0-12.5	19	1	0	
	12.9-16.2	19	1	0	G. 7
	16.4-18.6	19	0	0	-25
	18.8-19.2-2.6	19	0	0	
33	2.0-9.0	20	1	1(1Y)	G. 17
	9.4-12.2	20	0	0	
	13.4-15.4	20	0	0	-11
34	.5-10.0	15	0	1	
	10.4-14.4	15	0	2	G. 10
	15.1-17.3	15	0	0	
	17.3-18.2	15	0	0	-19
	17.0-gr.	15	4	0	
35	5.0-8.0	15	5	0	
	9.0-12.4	12	0	0	
	13.8-15.8	12	0	0	G. 14
	16.0-17.2	12	0	0	
	17.6-16.6	18	3	0	-16
36	2.0-	33	42	2	
	2.0-	33	28	2	
	1.0-	33	3	1	
	.5-	33	9	6	
	.5	33	6	4	G. 23.8
37	.5-7.6	15	2	1	G. 17
	7.8-12.4	15	1	2	
	13.0-15.4	15	0	3	- 1
38	.4-9.8	20	1	0	
	10.0-13.2	20	1	0	
	13.7-15.6	20	1	0	
	15.8-16.4-8.0	20	0	0	
	7.6-1.5	20	1	0	
39	gr. -9.0	15	3	0	
	9.1-14.1	15	0	0	
	14.2-17.2	15	4	0	
	17.3-18.4	15	2	0	

TABLE III—cont.

Flight No.	Altitude 1000 ft.	Minutes exposed	Bact.	Molds	Temp. °C.
40	gr. -4.0	13	0	0	
	9.5-13.8	13	0	0	
	14.0-15.8	13	1	0	

G.—Temperature at ground.

Y—Yeast cells.

gr.—Approaching ground—exact distance not recorded.

On numerous exposures bacteria were obtained when molds were absent. The converse is sometimes true also. No general rule can be made to cover all observations, but no entire flight was made in which all exposures were sterile.

In some flights somewhat larger counts for bacteria have been obtained at the lower levels, but this was reversed in flights on other days. One notable exception is Flight 21, where the lower exposures show no micro-organisms, then during an exposure from 16,000 to 17,200 feet some bacteria and a yeast cell were obtained. After another sterile exposure, the highest level attained in these flights (19,600-20,600 feet) showed the presence of bacteria and molds. Somewhat similar findings in some other flights would seem to indicate the possibility of definite strata, in which the micro-organisms may be present in somewhat higher concentration, due to conditions of temperature, humidity, and air movement which are of great importance in the formation and stratification of air masses. Precipitation must also play an important role in the distribution of bacteria.

The results obtained are not strictly comparable to those obtained by others noted in the literature, as the methods used previously have been decidedly different. They present the possibility of comparison with one statement of Meier, Stevenson, and Charles, to the effect that there is a decided thinning out of fungi above 8,000 feet. As a number of the exposures were made under 9,000 feet, exposures made above and below that height were tabulated and compared. These results are summarized together with those of another group, which contains the counts only from exposures at elevations above 15,000 feet.

TABLE IV.
COMPARISON OF RESULTS OBTAINED FROM EXPOSURES AT VARIOUS
ALTITUDES.

Total Exposures, each over 10 minutes.....	173
Exposures in which living micro-organisms were found.....	100
Exposures made at altitudes lower than 9,000 feet.....	74
Exposures in which living micro-organisms were found.....	50 (67.6%)
Exposures made at altitudes above 9,000 feet.....	99
Exposures in which living micro-organisms were found.....	50 (50.5%)
All exposures made at altitudes above 15,000 feet.....	34
Exposures in which micro-organisms were found.....	12 (35.3%)

These summarized results should be interpreted as only exhibiting trends, however, because numerous individual exposures in each group were found to be sterile. The trend, as indicated by these comparisons, is for a decrease at higher levels in the percentage of exposures showing micro-organisms. This may be an apparent rather than a true decrease, as the time factor has not been considered.

It may be stated that one is likely to find bacteria at any level up to and including the highest altitude reached in this study, namely, about 20,000 feet.

Flight 36, which was conducted primarily for the collection of gypsy moth larvae in connection with the Bureau of Entomology of the U. S. Department of Agriculture, offered an opportunity of making a series of long collections at definite altitudes. A report on the entomological aspects of these flights is presented elsewhere by Collins and Baker.⁶ The exposures made for bacteria and molds on this flight showed higher counts at 2,000 feet than at either 1,000 feet or 500 feet. These findings suggest the presence of larger numbers of micro-organisms in the higher air strata, under certain atmospheric conditions, than may be present in somewhat lower strata at the same time.

Types of Bacteria Isolated.

A group of 295 bacterial cultures were picked from typical colonies obtained from upper air exposures. After the common dilution-plate methods, these cultures were stained and their morphology determined.

⁶ Collins, C. W. and Baker, W. L. Exploring the Upper Air for Wind-borne Gypsy Moth Larvae. Jour. Econ. Entomology, 27, (2): 320-327. 1934.

Of these, 154, or 52.2% were spore-forming bacteria or bacilli. Non-spore-forming rods constituted 20%, or 59 organisms in the group, and cocci made up the remaining 82 cultures, or 27.8%.

More than half of the bacteria were spore-formers, which are notably more resistant to drying, cold, and other adverse conditions, including in some instances at least, exposure to sunlight.

Gram stains have been made of 204 of the above organisms, with the following results:

	Gram +	Gram -	Total
Bacilli.....	82	27	109
Non-spore-formers....	37	4	41
Cocci.....	50	4	54

From this group, 49 cultures of bacteria have been positively identified, according to the characteristics outlined in Bergey's Manual of Determinative Bacteriology, 4th edition, 1934.

They were classified into families and species according to the morphological, physiological, and biochemical characteristics usually determined according to the standard methods of the Society of American Bacteriologists.

The cultures were found to include 29 species of bacteria, which are shown in Table V, together with the number of times each species was identified.

TABLE V.
SPECIES OF BACTERIA IDENTIFIED FROM AIR CULTURES AND NUMBER OF
TIMES EACH WAS IDENTIFIED.

<i>Family</i> — <i>Bacillaceae</i>		
<i>Bacillus albus</i>	1	<i>Achromobacter tiogense</i> 1
<i>B. atterimus</i>	1	<i>Flavobacterium breve</i> 1
<i>B. cereus</i>	5	<i>F. flavescens</i> 1
<i>B. freudenreichii</i>	1	<i>F. solare</i> 1
<i>B. globigii</i>	1	
<i>B. graveolens</i>	3	<i>Family</i> — <i>Coccaceae</i>
<i>B. luteus</i>	2	<i>Micrococcus candidus</i> 1
<i>B. mesentericus</i>	2	<i>M. conglomeratus</i> 2
<i>B. mycoides</i>	1	<i>M. ochraceus</i> 3
<i>B. nondiastaticus</i>	1	<i>M. percitreus</i> 2
<i>B. platychoma</i>	2	<i>M. perflavus</i> 1
<i>B. silvaticus</i>	3	<i>M. sensibilis</i> 1
<i>B. simplex</i>	1	<i>M. sphaeroides</i> 1
<i>B. subtilis</i>	6	<i>Rhondococcus corallinus</i> 1
<i>Achromobacter geniculatum</i>	1	<i>Sarcina citrea</i> 1
		<i>S. flava</i> 1

Of the total cultures of bacteria classified and identified, 30, or more than 50% are members of the Family Bacillaceae, which are the resistant spore-formers.

The most common species found were *B. cereus* and *B. subtilis*, both of which were isolated and identified in six different cases. Every species identified was found to be one which is commonly found in the soil, water, or air.

It is interesting to note that no pathogens were found. Neither *Escherichia coli* (*B. coli*) or similar intestinal types were found.

In the 155 bacteria which have not yet been identified, although their characteristics have been determined, certain chemical characteristics are interesting. Practically none of these cultures has the ability to ferment the common sugars with the formation of gas. Another feature that many have in common is the inability to produce indol. In many respects they resemble various species which are listed above, but differ in some of the characteristics.

MOLDS.

The data in Table III indicate the presence of molds in the air to a considerable height. Their occurrence seems subject to considerable variation and the numbers collected, using the methods outlined, are low. The largest counts are shown in Flight 3, where all the exposures had over 70 molds. A considerable number of flights collected no molds. It seems likely that the molds in the air are rather irregularly distributed, as some flights show molds to be present at high altitudes, (19,600 feet in Flight 21) and absent near the ground. In some instances they seem to be present at all altitudes, and in some other flights more numerous at lower altitudes, as in Flight 31. No attempt was made to draw quantitative conclusions, but there are indications that altitude is not a factor of great significance in respect to mold distribution. That molds can be lifted from the earth to considerable distances, as shown in Flight 21, may well be significant to those concerned with the spread of plant diseases caused by fungi.

It must be emphasized that only those types of molds which grow readily in nutrient agar would be expected in these findings. As it was necessary to grow the bacteria on the same media, it was essential that nutrient agar be used.

Types of Molds Isolated.

Typical colonies of molds obtained in the Petri dishes were subsequently transferred with aseptic precautions to test tubes. These

cultures were later plated in dilutions to assure relatively pure cultures, which were subsequently examined microscopically.

Examination of 128 mold cultures which were from typical colonies found on the Petri dishes, gave evidence that 57 of the molds were *Aspergilli* and 36 of the remainder were *Penicillia*.

Of the remainder, molds of the following genera have been partially identified: *Alternaria*, *Cladosporium*, *Helminthosporium*, *Monilia*, *Trichoderma*. Others await identification.

YEASTS.

A number of colonies which developed on the Petri dishes from the air collections resembled yeast colonies in appearance. Each of these was later transferred to malt extract broth and incubated for 48 hours at 30° C. At the end of this incubation period, a hanging drop culture was made and the preparation examined microscopically to determine whether the cells reproduced by budding.

Of those cultures examined, 18 resembled yeast from a morphological standpoint, but none of these cultures was capable of fermenting either sucrose or dextrose with the formation of gas.

Four other cultures were isolated in this group which resembled yeast in size but formed a filamentous branching mycelium. One of these, very dark in color, appeared to have characteristics similar to *Torula niger*.

ACTINOMYCETES.

Several cultures were found to be members of that group intermediate between bacteria and molds, the Actinomycetes. No efforts have been made to carry these identifications further. These organisms are usually soil organisms.

COMPARISON OF BIOLOGICAL DATA WITH ATMOSPHERIC CONDITIONS.

Table VI is a compilation of the total numbers of micro-organisms, together with such factors as temperature, weather observations at the time of flight, precipitation on day of flight and the day previous, wind direction and velocities at different altitudes. At the left of the table is the collection time, which varies in different flights to a considerable extent.

It can readily be seen that the biological results obtained on each flight are subject to a number of widely fluctuating variables. Comparisons are difficult under such circumstances.

In general, more bacteria were obtained on any specific flight than

molds, although Flight 3 is a notable exception. No flights were made which did not show bacteria in at least one exposure. Thirteen flights were made during which no molds were collected.

There is possibly a slight indication of lower micro-organism counts on flights made on days following precipitation. With such small numbers of micro-organisms, however, any change in counts within the range shown would appear to be incapable of exact interpretation.

No definite relation of micro-organisms to either wind direction or velocity is apparent. It had been hoped that this compilation would show more definite relations between some of the factors concerned. Some idea may be gained, however, of the changes in direction and velocity of the wind currents in the upper air to which floating micro-organisms must be subject.

The temperatures are such at the higher altitudes that it would seem that only those organisms capable of sustaining themselves in very severe temperatures could exist.

TABLE VI.
MICRO-ORGANISMS AND ATMOSPHERIC CONDITIONS.

Flight	Collection time (min.)	Total Bact.	Total molds	Tempera- ture C.°		Weather Obser- vations at time of flight	Precipi- tation		Wind direction	Altitude in meters	Wind velocity meters/sec.
				Ceiling	Ground		Day of Flight	Previous Day			
1	50	30	12	-21.5	2.6	Partly cloudy		2R	WNW	500	12
2	30	32	26	-26.5	4.5	Heavy clouding overcast			WNW	0	11
									W	1500	27
									WNW	500	31
3		19	252	-22.5	1.0	Slight clouding on horizon			W	0	9
									WNW	2100	20
									NW	1000	14
4	50	6	6	-31.5	2.8	Clear			W	0	3
									WNW	1500	28
									W	500	13
5	50	5	13	-22	-2	Clear			W	0	4
									W	4500	18
									WSW	2000	7
6	60	19	12	-18	-2	Partly cloudy			NNE	0	2
									N	1500	15
									N	500	19
7	60	5	5	-28	-1.5	Partly cloudy			NW	0	10
									NW	1000	4
									NNW	500	5
									NNW	0	4

TABLE VI—cont.

Flight	Collection time (min.)	Total Bact.	Total molds	Temperature C.°		Weather Observations at time of flight	Precipitation		Wind direction	Altitude in meters	Wind velocity meters/sec.
				Ceiling	Ground		Day of Flight	Previous day			
8	60	11	12	-22	0	Clear			WNW	2400	17
									NW	1500	9
									W	0	3
9	60	2	3	-33	3	Overcast, heavy clouds	7S		NW	1200	15
									WNW	500	14
									WNW	0	7
10	60	11	2	-30	-12	Clear			NNW	1800	14
									NNW	1000	18
									NW	0	7
11	44	7	10	-17	-2	Overcast, heavy clouds			W	2500	15
									WSW	1000	14
									SSW	0	3
12		4	12	-13	13	Overcast, heavy clouds					
13	60	21	0	-22	-12	Light clouding			WNW	1400	31
									WNW	500	17
									WNW	0	12
14	83	28	0	-32	-6	Clear			NW	2500	23
									WNW	1000	13
									W	0	6
15	74	10	43	-27	2	Overcast, heavy clouds			WSW	2000	20
									WSW	1000	21
									SSW	0	5
16	45	1	1	-39	4	Light haziness	11R		WSW	3500	19
									W	1500	20
									W	0	4
17	60	1	2	-30	9	Light cloudiness					
18	75	5	1	-34	4	Clear			1R		
									NW	4000	26
									NW	1500	16
									W	0	4
19	100	5	0	-32	+1	Heavy clouds snow	1R		N	800	9
							13S		NNW	500	14
									NW	0	7
20	60	3	0	-29	0	Heavy clouds sleet			2R	1200	10
									17S	500	10
									NW	0	5
21	79	10	2	-36	-11	Clear			NW	2500	36
									NW	1000	24
									WNW	0	9
22	51	11	0	-27	-4	Clear			5R	2000	24
									NW	1000	18
									WNW	0	7
23	75	2	1	-23	3	Partly cloudy			WSW	3000	14
									W	1500	16
									SW	0	5

TABLE VI—cont.

Flight	Collection time (min.)	Total Bact.	Total molds	Temperature C.°		Weather Observations at time of flight	Precipitation		Wind direction	Altitude in meters	Wind velocity meters/sec.
				Ceiling	Ground		Day of flight	Previous day			
24	75	4	0	-25	4	Partly cloudy			WNW	2500	27
									NW	1000	21
									WNW	0	4
25	75	6	0	-38	3	Partly cloudy	3R		N	2500	19
							1S		NNE	1500	17
									NNW	0	7
26	60	1	0	-31	5	Clear			NNW	3000	22
									NNW	1500	22
									NW	0	6
27	100	21	3	-10	9	Overcast, rain	8R		WNW	5000	18
									NE	500	5
									NNW	0	1
28	100	1	1	-17	13	Cloudy	3M	13M			
29	78	4	0	-20	9	Clear, cloudy above ceiling			NE	5500	4
									ENE	1500	10
									W	0	2
30	48	4	1	-25	2	Clear					
31	68	31	24	-21	14	Overcast, snow near ceiling	3R		W	3500	15
									WSW	1500	14
									SW	0	4
32	76	2	0	-25	7	Clear			WNW	4400	28
									W	2000	18
									WSW	0	3
33	60	1	1	-11	17	Cloudy					
34	73	4	3	-19	10	Clear			WNW	5000	16
									NW	2000	10
									N	0	1
35	69	8	0	-16	14	Clear		5M			
36	165	88	15			Clear					
37	45	3	6	-1	17	Overcast, rain					
38	100	4	0	-7	14	Hazy			SSE	500	3
									SSE	200	4
									SE	0	2
39	60	9	0								
40	39	1	0								

S = snow for 1 hour.

R = rain for 1 hour.

M = mist for 1 hour.

LOWER TEMPERATURE AND ITS RELATION TO ISOLATED ORGANISMS.

One hundred and five pure cultures of bacteria which had been isolated from air samples taken at altitudes greater than 9,000 feet

were used for an experiment which is informative regarding the resistance of some of these organisms to low temperatures.

Transfers were made to fresh nutrient agar slants, after which the transfers were immediately placed in a mechanical refrigerator at 0° C. and left there for 49 days.

At this time, those cultures which showed any growth while incubated at 0° C. were placed in a tight metal container and refrigerated in an insulated box containing carbon dioxide snow. The temperature of this box was - 26° C. when the cultures were put in and after a forty-eight hour period they were taken out. At this time the temperature of the box interior was - 39° C. The cultures were then incubated at 20° C. for one week.

Of the 105 cultures, 36 were able to *grow* at 0° C. and of these 36, there were 31 which were able to grow after 48 hours at a temperature lower than - 26° C.

A similar experiment with a *Torula* culture, having characteristics similar to *T. niger*, showed that organism also was able to survive similar low temperatures and grow well at ordinary refrigerator temperatures.

POLLEN.

During the flight collections there have been collected eight different forms, Fig. 6, which appeared to be pollen grains and these have been observed and measured. Unfortunately, it was impossible to preserve these specimens because the paper filters were later shaken in distilled water previous to plating out for micro-organisms.

On Flight 8, one specimen (A) was obtained between 11,000-14,000 feet in altitude. A few days later, on Flight 9, another specimen of the same appearance was obtained between 3,000-9,500 feet.

The examination of filters from Flight 14 showed the presence of a pollen grain (B) in the air between 14,700-17,500 feet. A different type (C) was trapped between 17,600 and 18,800 feet on the same flight.

Flight 21 was the source of one pollen grain (E), at an exposure which lasted from an altitude of 16,000 to 17,300 feet.

The specimens previous to those obtained in Flight 36 were found singly. On this flight, which took place at relatively low altitudes, (500 to 2000 feet) there were 102 pollen grains trapped at the 2000 foot level, 98 at the 1000 foot level and 172 at the 500 foot level. The same pollen (F) was found in small numbers on Flight 37.

In addition, two different types of pollen were found on Flight 37,

one (G) being taken in the sample below 7,600 feet, and a second (H) in the exposure between 7,800 to 12,400 feet.

Several difficulties prevent the definite identification of these pollen grains. One of these is the fact that pollen grains are likely to alter their appearance under different conditions of humidity. In this

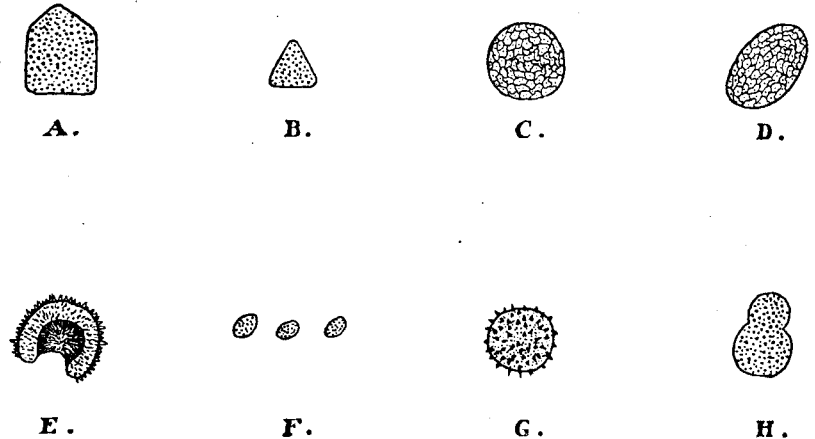


FIGURE 6. Pollen forms observed in upper air collections.

Form	Source Flight No.	Altitude (feet)	Size μ
A	8	11,000-14,000	107
	9	3,000-9,500	
B	14	14,700-17,500	72
C	14	17,600-18,700	118
D		11,500-ground	125
E	21	16,000-17,300	88
F	36	2,000	39
G	37	7,600-500	73
H	37	7,800-12,400	52

investigation there was no way of determining the humidity. Neither could the mounting of the pollens be changed to observe them in different positions, which would have been most helpful. Any change in position, mounting, or humidity was impossible because of the subsequent procedures which were undertaken for other purposes.

No attempt has been made to classify these pollens. An examination of the literature suggests the possibility that some of those found

may be members of the Pinaceae, (conifers) Caprifoliaceae, (honeysuckles) or the Ranunculaceae, the buttercups, but due to the factors mentioned above, any definite conclusions seem unfounded.

It is very interesting, however, to note that these pollens have been obtained at heights of over 16,000 feet on at least two occasions and several times at over 10,000 feet.

These observations indicate the wide areas over which plants which produce wind-borne pollens may be pollinated.

DUST COUNTS AND THEIR RELATION TO MICRO-ORGANISM COUNTS.

The disk collectors mentioned above were examined microscopically for dust particles in the same glass cell for pollen studies. These examinations, conducted on the paper exposure disks used in 17 flights, were carried out by means of a microscope with a mechanical stage. The dust counts included the enumeration of all observed dust particles.

As one disk was always used as a control during the collections, the control disk was counted also. In spite of the fact that these disks were washed in chloroform before using, there were still some particles on the disks previous to exposure. The average number of dust particles observed in the control disks was therefore assumed to represent the number of particles on each disk and therefore subtracted from the count obtained. Micro-organism counts were carried out on the same exposures.

The following results were obtained from the dust counts on 17 flights:

Average actual dust count per disk	323.2
Average dust particles per control disk	95.4
Average dust particles per exposure	227.8
Average bacteria count, same exposures	1.53
Average mold count, same exposures	.58

As the mold and bacteria counts were made from the very same disks on which the microscopic dust counts were made, the time element and altitude in each was identical.

This indicates a ratio of micro-organisms (bacteria and molds) of 2.11 to 227.8 dust particles, or 1 micro-organism to 107.95 dust particles.

The same procedure was followed using the data obtained only in the exposures which were made entirely above 9,000 feet. The results obtained in this manner are shown below:

Average dust particle count per disk.....	266.2
Average dust particles per control disk.....	<u>95.4</u>
Average dust particles per exposure above 9,000 ft.....	170.8
Average bacteria count, same exposures.....	1.25
Average mold count, same exposures.....	.20

In this series a ratio of 1 micro-organism to 117.93 dust particles was obtained.

The large number of dust particles to living micro-organisms is particularly interesting. In these flights, taken in part of a busy industrial region it is not entirely surprising to note a considerable quantity of dust. Doubtless part of it comes from the smoke stacks which emit vast clouds of dust at various intervals. Possibly part of it originates from the soil wended upward by convection currents. It is not without the realms of possibility that a part of this dust is of meteoric origin. One other possible source suggested itself, namely, the presence of exhaust dust from the engine of the plane.

The latter was ruled out by an experiment whereby ammonia and hydrochloric acid were blown through two separate glass tubes joined together at the end of the motor exhaust, which is under the plane. The cloud of ammonium chloride which formed, showed that the flue gases are not conducted near the inlet tube of the micro-collector, which is on the roof of the plane.

The seeming low ratio of micro-organisms to dust may also be partly due to the actinic exposure of the sun which may be lethal to certain micro-organisms. In the opinion of some meteorologists it may require several days during the winter season for air masses to attain an altitude of eighteen thousand feet. If such is the case it is conceivable that the sun's rays might cut down the numbers of micro-organisms. The earlier mentioned preponderance of spore-forming rods in the air samples is also suggestive of this possibility.

A continuation of these investigations of dust in the air, together with the collection of such information as can be obtained regarding living micro-organisms is now under way.

DISCUSSION.

The results obtained from these micro-biological collections of the upper air suggest certain observations.

The biological population of the upper air is probably an ever-changing one, never constant either in type or distribution, due to the many factors which may interact at the same time. These factors include temperature, humidity, wind direction and velocity, precipita-

tion, contamination from the earth's surface, seasonal growth of certain plants, and doubtless others which are less obvious.

Such results as have been obtained in this work suggest that bacteria, molds, and pollens may be expected at any height included in these experiments, namely, up to 20,000 feet.

A study of the types of micro-organisms found indicate the preponderance of soil types, as might well be expected. Among the bacteria, the Bacillaceae were found particularly prevalent, with two species, *B. cereus*, and *B. subtilis* outstanding. Each of these species is a spore-former and relatively resistant to unfavorable conditions. The two outstanding genera of molds identified were *Aspergillus* and *Penicillium*, and these types are also among the more resistant to unfavorable conditions.

The height which is reached by some of these forms induces speculation regarding the horizontal movement of some of these microscopic forms. If they can go up three and four miles in the air it would seem likely that their travels in a horizontal plane might be almost limitless. Such considerations make it very easy to understand how plant diseases may be transmitted through the travels of spores.

The findings of possible biologic strata, as is suggested in Flight 21, may be the result of the moving in of an air mass at high altitude from a considerable distance. As just a few days previous to this flight there had been heavy snows in this area, the possibility of surface organisms being the organisms found is somewhat remote. It is not considered that the findings on this flight warrant such a definite conclusion, but they are quite suggestive.

The dust collections suggest further studies to determine the comparable numbers of dust particles away from the gross contamination of the metropolitan areas. Some suggestion of a decrease of these particles at higher levels has been noted. The ratio of dust particles to living organisms may be of some significance, in that if one found an extremely high ratio it might indicate something of the history of the air mass, either that the dust had long been exposed to actinic rays or that its origin was from some industrial area.

These studies indicate that we have a sheath of air around us, containing irregularly dispersed living micro-organisms, which is in a constant state of flux due to conditions inherent to the atmosphere. The types present include bacteria, molds, yeast, and actinomyces. In this same air we find dust and other suspended materials such as pollen which are subject to these same ever-changing conditions. The results obtained suggest that further and more extended investigations

of a similar nature might yield helpful information regarding the various factors which bring about the changes.

SUMMARY.

A report was made on the findings obtained from 45 airplane flights during which 201 separate collections of micro-organisms at various levels in the upper air, up to 20,600 feet, were made. Bacteria and molds were found above 19,600 feet. Yeasts and pollens were found above 16,000 feet. Spore forming bacteria were the predominant micro-organisms. Twenty-nine species of bacteria were identified. *Aspergilli* and *Penicillia* were the predominating molds found. Dust counts were made on 17 flights and evidence was presented that these counts decrease somewhat at the higher levels.

The results of an experiment conducted to demonstrate the resistance of certain isolated bacteria to cold were included.

ACKNOWLEDGEMENTS.

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An acknowledgement should also be made to the Rockefeller Foundation for grants of financial assistance which enabled the plane to be operated on its normal mission. Especial thanks are due the writer's assistant, Mr. J. T. R. Nickerson, for his efficient service in conducting a considerable part of the laboratory work. To Dr. R. Schuler of the Stanco Laboratory in Elizabeth, N. J., thanks are due for the low freezing hydro-carbon oil furnished for the collector.

Note: The sad and untimely death by accident of Lieutenant Henry B. Harris on June 15, 1934, while participating in other activities pertaining to aviation, has removed a faithful and efficient colleague. His coöperation and personal effort in making many of the biological collections, often under difficult circumstances, in addition to his manifold duties as meteorological observer and pilot, have been indispensable in this investigation.

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A STUDY OF THE ANT GENERA NOVOMESSOR
AND VEROMESSOR.

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WITH TWO PLATES.

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It has long been known that there are few endemic genera of ants in the portion of America which lies north of the tropics. The great majority of the genera in our temperate area are also found in Europe and northern Asia or belong to the large southern component of our fauna which is simply an extension of Neotropical groups. Of our native genera which, of course, do not belong in either of the above categories, there are less than a dozen all told. Because of its peculiar faunal composition one might suppose that this small endemic ant fauna of North America would have attracted special attention. Actually, however, the very limited citation of many of these forms in myrmecological literature appears to indicate that the opposite has been the case. For this lack of observation the myrmecologist cannot altogether be blamed. A number of the species belonging to these genera are rare and are frequently confined to areas whose inaccessibility or climate renders field work difficult. In the case of the two genera discussed in this paper there is the added difficulty of specific recognition, since the literature contains no keys to the various species. While the ecological data presented in this paper are often all too scanty, the authors trust that the publication of an adequate taxonomic analysis of the species belonging to the genera *Novomessor* and *Veromessor* may serve as a stimulus for the observations needed to round out our knowledge of these interesting insects.

The greater portion of the material upon which this study is based is in the collection of the senior author and was in large part secured by him during trips to the southwestern United States in 1905, '10, '17, and '28. This material has been augmented by specimens taken by the junior author during the summers of '32 and '33. In addition, through the courtesy of Dr. W. M. Mann, we have been able to examine his valuable collection which contained several new forms herein described. The authors wish to express to Dr. Mann their sincere appreciation of his kindness. Dr. M. R. Smith has also very kindly contributed specimens for which we wish to thank him.

It seems necessary at the outset to stress the fact that *Novomessor* and *Veromessor* have little in common except a preference for arid country. In structure, nesting habits, and phylogenetic relationships the two genera are distinctly different. Indeed one may note a difference in their geographical distribution for, despite the fact that both are customarily regarded as Sonoran, their ranges are in large part separate. That confusion has resulted in the past from their inclusion in a single group will be shown in the sequel.

The taxonomic history of the two genera is not particularly involved. Following Mayr's original description of *albisetosus* in 1886 the species in our present genus *Novomessor* were ordinarily regarded as belonging to *Ischnomyrmex*, which was at that time held to be a subgenus of *Aphaenogaster*. The species which we now assign to the genus *Veromessor* were usually considered to be American representatives of the Old World *Messor*. There is something to be said in defense of such a view. At least it separates the two distinctly different groups which Emery in 1915 (1)¹ united to form the genus *Novomessor*. There can be no question but that Emery intended to relieve the genera *Aphaenogaster* and *Messor* of incongruous species. It is strange, however, since he was able to evaluate the relatively slight differences which separate *Novomessor* and *Aphaenogaster* as matters of generic consequence, that he should have failed to realize the much greater differences between *Novomessor* and *Veromessor*. The matter becomes even more incomprehensible when one reflects that Emery himself described *Veromessor stoddardi*, one of the most outstanding species in the genus.

The inconsistency of Emery's view was partly corrected two years later by Forel who in 1917 (2)¹ separated the genus *Novomessor* into two groups. *Novomessor sensu strictu* received the species *albisetosus*, *cockerelli*, and *sonorae*, while the subgenus *Veromessor* was set up for *andrei*, *julianus*, *pergandei*, and *stoddardi*. Except for the addition of the species *chamberlini* and *relictus* to the subgenus *Veromessor* this was the plan followed by Emery in the *Genera Insectorum* (3).¹ Finally in 1922 (4) the senior author gave to *Veromessor* its present

¹ In Emery's paper of 1915 and also that of Forel in 1917 no descriptive matter of value for specific diagnosis appears. The various species are merely listed in each paper. This is also true of the listing in the *Genera Insectorum*. In order to simplify the synonymies of the various species references to the above listings have been omitted. They will be found in the bibliography at the end of the paper.

generic status. There is no reason to take up here the various phylogenetic considerations which have led to the groupings just considered. These will be presented in the discussion of each genus in the body of the paper.

NOVOMESSOR Emery.

Novomessor Emery, Rend. Accad. Sc. Bologna, p. 73, (1915).

Forel, Bull. Soc. Vaud. Sci. Nat. Vol. 51, p. 235, (1917).

The genus *Novomessor* as defined in the present paper contains three species, *albisetosus* Mayr, *cockerelli* Ern. André, and *manni*, a new species described below. The authors are of the opinion that Pergande's species *sonorae* is a synonym of *cockerelli*. Both of these names were published in the year 1893, but since André's paper has precedence by several months, the name *cockerelli* has priority.

As has already been stated in the introduction, the genus *Novomessor* is related to *Aphaenogaster*. This relationship is so close that it is very unlikely that *Novomessor* could be confused with any other genus. We need, therefore, consider only the way in which the two differ. In presenting the structural criteria which distinguish them it is first necessary to make a qualifying statement in regard to *Aphaenogaster*. It happens that this genus is highly heterogeneous in structure, a fact which makes comparison difficult. Nevertheless, with the exception of the Papuan subgenus *Planimyrma*, it is possible to make a generalization applicable to the remainder of the species. In the worker of *Aphaenogaster* the mesoepinotal suture is always well developed. Moreover, the thoracic dorsum bears, at the suture, a distinct impression which is usually rather narrow. The result is to set off the epinotum sharply from the rest of the thorax. In the worker of *Novomessor*, on the other hand, the mesoepinotal suture is entirely absent on the dorsum and upper parts of the sides of the thorax. All that is left of it is a short groove which does not extend above the level of the meso- and metapleurae. The dorsum of the thorax is unimpressed or, if an impression is present, it takes the form of a broad shallow concavity. The epinotum is, therefore, not sharply set off from the rest of the thorax as in *Aphaenogaster*. Oddly enough, the condition just described is also found in the thorax of the worker of *Planimyrma*.

While the thoracic differences outlined above are rather more subtle than one might expect in the case of two distinct genera they appear to be the only differential characters of any consequence. From a practical standpoint the large size of the worker and female

of *Novomessor* serves to distinguish them from any of the North American *Aphaenogasters*, but it is obvious, that this size difference has a limited application since there are other species of *Aphaenogaster* whose size more nearly approaches the size of *Novomessor*. In the case of the male caste the problem is even more difficult since the males of *Novomessor* are smaller than one would expect in view of the size of the female. The resemblance between these males and those of some of the more primitive species in the genus *Aphaenogaster* is so complete that the authors have been unable to discover any structural character peculiar to the males of the genus *Novomessor*. While this similarity bears out Emery's belief that *Novomessor* is a derivative of *Attomyrma*, it must be remembered that the species which at present make up the subgenus *Attomyrma* are by no means uniform in their degree of specialization. For this reason it is necessary to restrict the relationship of *Novomessor* to the more primitive species of *Attomyrma*, since a number of species belonging to *Attomyrma* show a degree of specialization considerably greater than that found in *Novomessor*. These advanced species (*gibbosa*, *spendida*, etc.) certainly cannot be regarded as an ancestral stock.

As Emery has shown,² there are several genera of xerophilous ants whose relationship can be traced directly to other genera which are not xerophilous. Thus Emery regards the Sonoran *Myrmecocystus* as a derivative of *Lasius*, the North African *Cataglyphis* as a derivative of *Formica*, and the Australian *Melophorus* as a derivative of the *Plagiolepis* group. It happens that all three of these xerophilous genera show ecological peculiarities and structural modifications that indicate a high degree of adaptation to desert life. This is not the case with *Novomessor*. There is little structural modification and practically no trophic adaptation which would mark them as well-developed xerophiles. This may best be explained on the assumption that *Novomessor* has only recently entered the desert areas which it now occupies. This does not mean, however, that *Novomessor* has had a recent origin. On the contrary, it appears to be an old group which has at some comparatively recent time been forced into desert areas through pressure from more highly developed forms.

It is fortunate that other problems connected with *Novomessor* are less vexing than the question of its phylogeny. Although far from complete our distributional records and ecological data give us

² Emery, Zool. Jahrb. Sup. 15, Band 1, (1912) p. 95 *et seq.*

a fair idea of the range and habits of the two northern representatives of the genus. The southern end of the range is at present Colima, Mexico, the type locality of the new species *manni*. It is to be regretted that so little is known of this species since it appears to be the most primitive member of the genus, and a better knowledge of its range and habits might throw light on the origin of the group. Since *manni* is known only from Colima and since nothing is known of its habits, our discussion of *Novomessor* must deal almost entirely with the two other species. As may be seen from the accompanying map the ranges of *cockerelli* and *albisetosus* are largely coextensive within the United States. *Cockerelli*, however, swings well to the south of *albisetosus*, specimens having been taken as far south as Zacatecas, Mexico. It may be noted that such southern specimens occur at higher elevations (7000 feet) than do those in the United States. The absence of Mexican records for *albisetosus* is puzzling, for it must certainly occur there as is indicated by its presence in the Chisos Mts., in southern Texas, which are only a few miles north of the Mexican border. To date, however, the locality just mentioned represents the known southern limit of the range of *albisetosus*. In the United States both species occur throughout a relatively narrow band which extends for approximately eight hundred miles from Del Rio, Texas, to Gila Bend, Arizona. In this area both nest on arid plateaus whose elevation varies from twenty-five hundred to five thousand feet. They do not as a rule descend below twenty-five hundred feet. Indeed their absence from the Mojave and Imperial Deserts appears to be due to their dependence upon elevation. To the casual observer *cockerelli* will appear to be the more abundant of the two, since it prefers to nest on the open plains, avoiding as a rule the isolated mountains which occur throughout its range. Its distribution is, consequently, more nearly uniform than that of *albisetosus*, since the latter usually founds its colonies in the foothills of the mountains and for this reason is absent over wide areas where *cockerelli* occurs in abundance. This difference in the choice of nest sites is not easy to explain. Certainly elevation has little or nothing to do with it. One of the few areas in which the two species occur together is the Davis Mts. in Texas. Here the nests are in close proximity and yet, even under these circumstances, there is apparently a difference in the choice of sites. The nests of *cockerelli* are usually found in the level land near the stream bottoms while those of *albisetosus*, as a rule, occur on the sloping lower flanks of the

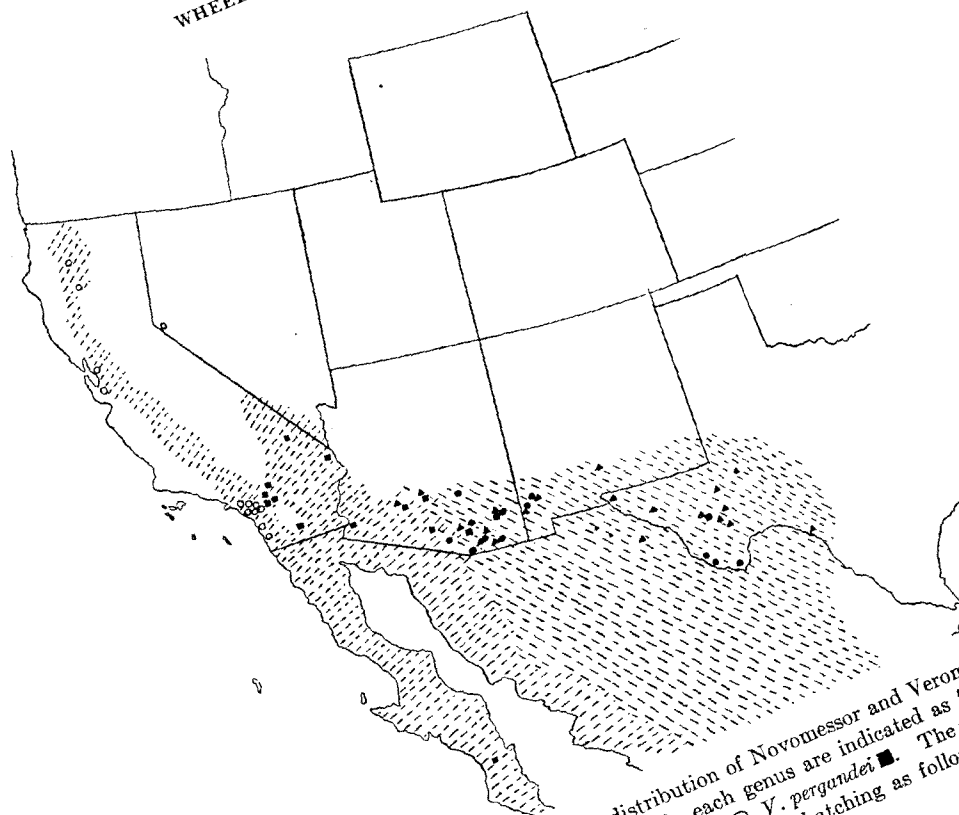


FIGURE 1. Map showing the distribution of Novomessor and Veromessor. The locality records for two species in each genus are indicated as follows: *N. albigulosus* ●, *N. cockerelli* ▲, *V. andrei* ○, *V. pergandei* ■. The probable ranges of the two genera are indicated by cross-hatching as follows: Veromessor [cross-hatched box], Novomessor [dotted box].

hills. Since the nests of the two species are frequently less than a mile apart and practically at the same elevation it is difficult to believe that in this case altitude could influence the choice of nest sites. It is unlikely that anyone who has seen the nests of these insects could have failed to be impressed with their extraordinary coarseness of construction. There is not a single feature of the nest which does

not appear abnormally large in view of the size of the insects themselves. The irregular central opening of the nest may be three or four inches across. Through this one looks down into a steeply descending, roughly constructed tunnel which more nearly resembles a rat's burrow than the entrance to an ant's nest. Around the central opening the insects ordinarily build a disc of very coarse gravel mixed with excavated soil. This disc may be six feet in diameter in the nests of *cockerelli*, but is usually smaller and sometimes absent in the nests of *albisetosus*. Towards the center of the disc there is often a thicker pile of soil and gravel which has been formed into a rude crater. Those nests of *albisetosus* which lack the disc and crater are generally constructed under stones but otherwise do not differ from the nests of the more common type.

During the summer months the foraging activities of these insects begin late in the afternoon and continue through the night hours. In the summer of '33 the junior author was able to observe the nocturnal activities of both species since each came regularly to collect small insects attracted to the camp light. As a rule by the middle of the morning the workers have returned to the nest where they remain during the midday hours. When foraging the workers do not form files. Each stalks slowly about in a deliberate manner, which gives it a ludicrous air of bland solemnity. It may be doubted if these insects are capable of quick movement since, even when disturbed, their best efforts at speed are neither rapid nor sustained. The workers show no particular preference for seeds since, in addition to these, they gather small bits of plant tissue, pieces of fruit, and the disarticulated parts of insects. The latter are probably secured from insects which are dead or in a moribund condition since the slow movements of *Novomessor* would scarcely permit successful predatism. Little if any of the various substances brought into the nest are stored there. It seems scarcely necessary to add that insects with such generalized feeding habits can scarcely be considered harvesters. It is possible to go one step further and question whether the ants of the genus *Novomessor*, despite their distribution, ought to be regarded as highly adapted xerophiles. Since trophic specialization of one sort or another is such a regular occurrence among the highly xerophilous species, its absence in a desert-dwelling group, such as *Novomessor*, can scarcely be without significance. The idea that *Novomessor* is not well adapted to desert life finds support in the character of the *ammochaetae* which these insects possess. As has been

pointed out by the senior author (5), the presence of these groups of hairs in an almost invariable feature among forms well adapted for desert life. This correlation is readily understandable when one considers that the ammochaetae are used to carry excavated dust or sand out of the burrows, a function which is particularly important in the case of desert-dwelling forms. The ammochaetae of the three species of *Novomessor* form an interesting developmental series. In *manni* the scattered hairs of the gula and mentum are scarcely longer than those on the other parts of the body. It cannot be said that this species possesses anything which could be called ammochaetae. In *cockerelli* some of the gular hairs are of fair length and recurved at the tip, but most of the hairs on the lower surface of the head are no longer than those elsewhere. There is no linear arrangement, as for example in *Pogonomyrmex*, of the long hairs which are scattered at random over the whole under surface of the head. In *albisetosus*, in which there are definite though poorly developed ammochaetae, the majority of the long hairs are segregated towards the sides of the head and, in addition, there are hairs along the lower surface of the mandibles. Of the three species there can be no question that *albisetosus* is the most specialized so far as ammochaetal development is concerned. Even so, its ammochaetae are far inferior to those of many xerophilous species and do not form what Santschi has called a "psammophore."

The workers of the three species of *Novomessor* may be separated by means of the following key:

1. Occiput prolonged posteriorly into a triangular neck which terminates in a distinct flange. *manni* sp. nov.
 Occiput not prolonged posteriorly, the occipital border flat in the middle or slightly convex, the occipital angles well marked. 2
2. Head, exclusive of the mandibles, very slightly or not at all longer than broad, with wavy longitudinal rugae extending almost to the occipital border, the latter granulose. *albisetosus* Mayr
 Head, exclusive of the mandibles, at least one and a third times as long as broad, with the wavy longitudinal rugae well developed only on the anterior half of the head, the posterior half with much feebler rugae, which are replaced toward the occiput with fine coriaceous sculpture. *cockerelli* Ern. André.

Novomessor albisetosus (Mayr.)

(Plate I, fig. 3).

N. albisetosus (Mayr), Verh. Zool-bot. Ges. Wien, Vol. 36, pp. 443, 446 (1886)
(*Aphaenogaster*).

Wheeler, Ants, p. 280, (1910).

This species is so well known and so easily recognized that a detailed description seems superfluous. That there could be any confusion of *albisetosus* with *manni* seems very unlikely since the unique head of the latter sets it off sharply from the other forms. The differences shown by *albisetosus* and *cockerelli*, on the other hand, while quite distinct are less obvious. Since these species are those ordinarily met with in collections, it seems advantageous to amplify the brief diagnostic remarks of the key by a more careful comparison.

As has been noted in the key, the head of *albisetosus* is shorter than that of *cockerelli*. There is also a difference in shape. In *albisetosus* the sides of the head in front of the eyes are subparallel but behind the eyes become convex, merging without an abrupt transition into the broadly rounded occipital angles. The posterior border of the head consequently appears evenly convex or if the median portion of the occipital border is flattened this flattening is not extensive. In *cockerelli* the sides of the head are feebly convex throughout and, since the occipital angles are much less rounded, the border of the occiput presents a broad flattened median portion which is bordered behind by a narrow flange.

In thoracic structure the two species are rather similar, except for the epinotal spines. In *albisetosus* these are at least as long as the basal face of the epinotum. In *cockerelli* they are considerably shorter. The other differences shown by the epinotal spines are less constant, but in most cases those of *albisetosus* are more nearly straight and more divergent than those of *cockerelli*. In *albisetosus* if the spines are bent at all the curve is downward, whereas in *cockerelli* the spines are ordinarily bent inward so that when seen from above they appear subparallel.

The most striking sculptural difference in the two species has already been noted in the key. In addition *albisetosus*, because of its heavier sculpture shows a uniformly greater degree of opacity than *cockerelli*. This is particularly noticeable in the case of the petiole which is almost completely opaque in *albisetosus* while in *cockerelli* at least the node and usually the lower portions as well are very shining. There is a good deal of variation in the cephalic sculp-

ture of *albisetosus* since in certain specimens the rugae proceed to the occipital border without being bent toward the center of the head. At the other extreme are those individuals in which the rugae turn inward sharply a short distance behind the eyes. In these the vertex is covered with prominent transverse rugae while the occiput is largely granulose. Although this difference is marked it is not constant and cannot be used as a basis for subspecific distinction.

Albisetosus is also much more hairy than *cockerelli*. In the former species the entire body is covered with numerous coarse whitish-yellow hairs. These taper from base to tip but are rather blunt particularly those on the epinotum and petiolar nodes. The cephalic hairs, which are abundant on the upper surface and sides of the head, are very variable in length. Those on the dorsum of the pro- and mesonotum are more uniform and of a length approximately equal to the longest cephalic hairs. A few short hairs occur on the epinotum and the petiolar nodes. The abdomen bears numerous hairs of quite uniform length but shorter than those of the pronotum. These abdominal hairs are most numerous on the posterior segments, thinning out toward the base of the postpetiole. In *cockerelli*, with the exception of two or three long hairs on the front of the head and a group on the ventral surface of the abdominal segments, the pilosity is uniformly short. It is also notably sparser in *cockerelli*. This difference is most noticeable on the upper surface of the gaster, which in *cockerelli* is entirely covered with evenly spaced hairs. Because of their shortness and infrequent occurrence these do not overlap like the gastric hairs of *albisetosus*.

The females of the two species may be separated easily on the basis of cephalic structure. The head of the female of *albisetosus* is only slightly longer than broad (mandibles excluded), with antennal scapes which in repose surpass the occipital border by a distance not exceeding the length of the first funicular joint. In most specimens the sides of the head taper inward from the mandibular insertions to the anterior border of the eyes but, even when this constriction is not well marked, the part of the head anterior to the eyes is noticeably narrower than the part behind them. In the female of *cockerelli* the head is decidedly longer than broad. No constriction of the anterior part of the head occurs and the sides of the head are straight or very feebly convex. The scapes in repose surpass the occipital border by a distance exceeding the length of the first funicular joint.

An additional and very striking difference between the females of

these two species is furnished by the thoracic structure. The entire thorax of the female of *albisetosus* is shorter and higher than that of *cockerelli*. The difference is most conspicuous in the epinotum. In *albisetosus* this region is so short that the basal and declivous faces meet at a very wide angle which might be considered a single sloping surface, were it not that the angular bases of the epinotal spines still preserve to some extent the point of junction. In *cockerelli*, since the epinotum is longer, the basal face is much less sloping and meets the declivous face at a well-marked angle.

In the female the differences in sculpture and pilosity are much less striking than in the worker, although distinctions do exist, notably the much more shining epinotum in the case of *cockerelli*. On the other hand, the head of the female of *cockerelli* is entirely rugose and it is considerably more hairy than the worker so that distinctions based upon sculpture and pilosity are of less value than in the case of the worker.

The males of *cockerelli* and *albisetosus* may also be readily distinguished. The somewhat smaller (6 mm.) male of *albisetosus* has a short head with the ocelli borne well back toward the occiput, which slopes strongly just behind them. Viewed from the side the two posterior ocelli mark an angle separating the occipital area from the front. The mesonotum of the thorax is covered with weak rugae, granulate and feebly shining, except for a narrow, strongly shining, median strip which extends entirely across the anterior half of the scutum. The notauli are indistinct. The male of *cockerelli* is larger (7.5 mm.), the head is much longer and there is no marked angle between the occiput and the front, the ocelli occurring well down on the head. The thorax is bulkier and more feebly sculptured, with a large shining triangular area on the scutum between well marked notauli.

No exact type locality is available for *albisetosus*. Mayr notes that the two specimens from which this species was originally described were taken by Norton in New Mexico. We have seen material from the following localities:

- Texas: Alamito, Presidio Co. (W. M. Wheeler.)
- Chisos Mts. (O. W. Williams and W. S. Creighton.)
- Ft. Davis Mts. (W. M. Wheeler, J. C. Bradley and W. S. Creighton.)
- Presidio. (W. C. McDuffie.)
- New Mexico: Lordsburg. (Cornell Univ. Exp.)

New Mexico: Steins. (W. M. Wheeler.)
 Arizona: Baboquivari Mts. (No collector.)
 Bisbee. (L. C. Murphree.)
 Bonita, Graham Co. (J. C. Bradley.)
 Coyote Mts. (No collector.)
 Globe. (H. C. Markman.)
 Huachuca Mts. (W. M. Wheeler and W. S. Creighton.)
 Nogales. (Oslar and L. C. Murphree.)
 Oracle. (W. M. Wheeler.)
 Pinaleno Mts. (W. M. Wheeler.)
 Texas Pass. (W. M. Wheeler.)

Novomessor cockerelli (Ern. André).

(Plate I, figs. 1 and 4.)

N. cockerelli (Ern. André), Rev. Ent. p. 150 (1893) (*Ischnomyrmex*).

Wheeler, Ants, pp. 273, 280, fig. 155 (1910).

N. sonorae (Pergande) Proc. Calif. Acad. Sci. (2) Vol. 4, p. 34 (1893)
 (*Aphaenogaster*).

The characteristics by means of which all three castes of this insect may be recognized have been given in the discussion of *albisetosus*. The habits of *cockerelli* have also been taken up in a previous paragraph. We shall, therefore, merely add the locality records for this species. The type locality is Montezuma, Chihuahua, Mexico (T. D. A. Cockerell). We have seen specimens from the following localities:

Arizona: Benson. (W. M. Wheeler.)
 Fenner Canyon, Santa Catalina Mts. (W. M. Wheeler.)
 Florence. (C. D. Lebert.)
 Gila Bend Mts. (W. M. Wheeler.)
 Hereford. (W. M. Wheeler.)
 Huachuca Mts. (C. R. Biedermann.)
 Oracle, Tempe, Tucson, and Yucca. (W. M. Wheeler.)
 New Mexico: Aden. (W. M. Wheeler.)
 Alamogordo. (G. von Krockow.)
 Lordsburg. (W. S. Creighton.)
 Steins. (W. M. Wheeler.)
 Texas: Alpine. (W. M. Wheeler, W. S. Creighton.)
 Del Rio. (W. M. Wheeler.)
 El Paso. (P. J. Darlington, J. C. Bradley.)

- Texas: Ft. Davis Mts. (W. M. Wheeler, J. C. Bradley, W. S. Creighton.)
 Ft. Stockton. (W. M. Wheeler.)
 Juno. (J. C. Bradley.)
 Langtry. (W. M. Wheeler.)
 Marathon. (W. S. Creighton.)
 Monahans. (W. M. Wheeler.)
 Sierra Blanca. (W. S. Creighton.)
 Terlingua and Toronto. (W. M. Wheeler.)
 Warfield. (W. S. Creighton.)
 Mexico: Cerro Carrizal, Chihuahua. (C. H. Townsend.)
 Pacheco, Zacatecas. (W. M. Wheeler.)

Novomessor manni sp. nov.

Worker: Length 10 mm. (Plate I, fig. 2.)

Head, exclusive of the mandibles, slightly less than twice as long as broad, widest just behind the eyes, the sides of the anterior half straight and only slightly tapering inward from the eye to the insertion of the mandibles; posterior to the eyes they are feebly convex and converge sharply toward the occiput where they form a flanged collar similar to that in certain species of *Aphaenogaster* (*arancoides* etc.). Clypeus rather flat above, truncate anteriorly with the lateral edges feebly arcuate. Mandibles large, triangular, with three apical teeth, the innermost tooth notably smaller and more obtuse than the other two, the remainder of the masticatory margin irregularly serrate but without definite denticles. Eyes prominent, strongly convex, subcircular in outline, placed slightly in front of the middle of the head. Frontal carinae well developed, strongly divergent anteriorly, parallel behind. Frontal area well defined, slightly but clearly depressed. Antennal scapes feebly curved, their thickness evenly increasing from base to tip. In repose they surpass the occipital margin by a distance equal to one quarter of their entire length. Funiculus filiform, the first joint much longer than any of the succeeding joints, which notably decrease in length though only slightly increasing in thickness from base to apex.

Thorax without sutures. Seen from above the pronotum is campanulate and twice as wide as the immediately adjacent portion of the mesonotum. Sides of the mesonotum moderately divergent behind, slightly wider than the epinotum, the latter narrowed in front but rectangular behind. Seen in profile the promesonotum

forms a single feeble and somewhat irregular convexity, the epinotum is flat throughout except for an anterior sinuosity where it joins the mesonotum. Epinotal spines long, their apical two-thirds slender, their bases somewhat thickened. Seen in profile they are virtually straight and almost parallel with the dorsum of the epinotum. Seen from above they are feebly divergent and slightly curved inward, with their thickened bases set close together.

Node of the petiole in profile low and evenly rounded above, its anterior face meeting the thick and tapering anterior peduncle in a well-marked angle, its posterior face confluent with the short posterior peduncle. Postpetiole in profile much narrowed in front, the dorsum feebly convex, the ventral surface straight in its anterior half and feebly sinuate behind. Seen from above the node of the petiole is suboval, scarcely wider than the peduncle, and less than half as wide as the pyriform postpetiole. Gaster large, oval.

Head and thorax ferruginous; petiolar nodes, epinotal spines, and legs clear yellowish red; antennal scapes and to a lesser extent the funiculi sordid, reddish brown; abdomen piceous brown. Mandibles shining, with feeble striae and numerous, coarse, piligerous punctures. Clypeus with a few, coarse, longitudinal striae which converge at its anterior edge. Head with numerous, coarse, wavy rugae extending diagonally from the genae across the front and uniting to form continuous, sharp, transverse rugae on the vertex. Area just behind the frontal carinae with longitudinal rugae. The spaces between them on the front and vertex are granulose, giving this portion of the head a duller appearance than elsewhere. Entire thorax strongly shining, the pronotum feebly shagreened; mesonotum and epinotum with prominent transverse rugae. Area between the base of the epinotal spines smooth. Petiole and postpetiole finely granulose, dull. Gaster smooth and very shining with sparse and minute, piligerous punctures. Hairs golden, sparse, short, stout, erect, or suberect; virtually absent on the mesonotum and epinotum, no longer on the under surface of the head than elsewhere. Tarsi and scapes covered with numerous rather fine, suberect hairs; funiculi pubescent.

Described from a single worker taken by Dr. W. M. Mann at Colima, Mexico.

VEROMESSOR Forel.

Veromessor Forel, Bull. Soc. Vaud. Sc. Nat. Vol. 51, p. 235, (1917) (*Novomessor* subgenus).

Veromessor Wheeler, Bull. Amer. Mus. Nat. Hist. Vol. 45, p. 661, 680, (1922).

As ordinarily defined the genus *Veromessor* contains seven species, *andrei*, *chamberlini*, *julianus*, *lobognathus*, *pergandei*, *relictus* and *stoddardi*. All of these have been previously described and no new species are added in the present paper. Dr. W. M. Mann has, however, been fortunate in discovering two new variants of *julianus* and the senior author two which belong to *andrei*.

It is difficult to make general statements which will apply to the genus *Veromessor* since its members vary widely in structure, habits, and faunistic affinities. These differences appear to be due to the long isolation of the various species, an isolation which must date back to the Cretaceous period to judge from the presence of *relictus* in Haiti. Since it is impractical to treat the genus as an ecological or zoögeographical unit, we have confined the introductory discussion to a consideration of those characteristics which have to do with the phylogeny of the group. This last is a matter badly in need of clarification. To date, the only attempt to explain the phylogenetic relationships of the genus *Veromessor* is that made by Emery in the *Genera Insectorum* (3). It has already been mentioned that in this publication Emery treated *Veromessor* as a subgenus of *Novomessor*. For this reason his phylogenetic considerations were applied to the entire group, a fact which now makes them confusing rather than helpful because of the subsequent separation of the two genera. However, if Emery's conception is to be considered at all, we must assume that his derivation was intended to apply to both genera. This being true, the authors cannot agree with Emery's ideas concerning the origin of the genus *Veromessor*. In his introductory statement on the genus *Novomessor* he wrote as follows: "This genus constitutes a group parallel to *Messor* in the new world but it is not derived from *Messor* nor is the reciprocal true. In my opinion *Novomessor* has had an independent origin and is descended from some species of *Attomyrma* which adapted itself to a graminivorous diet; in any case *Messor* cannot be derived from *Novomessor* because of the venation of the wings, which is more primitive in the former group." It is not difficult to show that Emery's derivation of *Veromessor* from *Attomyrma* is unsound. The structure of the males in the two groups presents what appears to be unquestionable evidence that *Attomyrma* cannot be ancestral to *Veromessor*. Among the more highly specialized genera in the tribe Pheidolini the males possess certain structural features of an advanced type. This is particularly apparent in the males of *Aphaenogaster*, *Pheidole*, and

Ischnomyrmex. In many of the species belonging to these genera the head of the male is undergoing a reduction in size which results in a shrinkage of the occipital margin behind the lateral ocelli, which, instead of being borne on the front, form a projecting crown at the top of the head, where the sides slope outward to the insertion of the mandibles. In addition there are thoracic alterations. The scutum has been enlarged at the expense of the other thoracic sclerites and this has resulted in the formation of a large overhanging bulge at the anterior edge of the scutum. The small pronotum is forced downward under the scutum and in extreme cases appears to lie on the ventral surface of the thorax. Either or both of these peculiarities may appear in the same insect. When both are well developed the result is apt to be rather incongruous, since there is produced a male whose absurdly small head is attached at a point on the thorax where one would expect to find the front coxae. On the other hand, the males of the more primitive *Pheidolini* do not show the configuration just described. This is particularly true of the males of *Messor*, in which the head is elongate, with subparallel sides, well-marked occipital angles, and the lateral ocelli borne well forward of the occipital margin. In the thorax the scutum only slightly overhangs the pronotum and is not disproportionately swollen. If *Veromessor* has been derived from *Attomyrma* as Emery postulates, we should certainly expect it to have males possessing the characteristics of the *Aphaenogaster* type. Actually the males of *Veromessor* are very similar to those of *Messor*. This is particularly true of the male of *pergandei*. The males of *Veromessor* must, therefore, be regarded as more primitive than those of *Attomyrma*.

While it is easy to demolish Emery's hypothesis, it is very difficult to replace it with another which cannot be questioned. Lack of adequate paleontological data for most of our Formicid genera reduces any discussion of phylogeny to a highly speculative and opinionated process. In the ensuing paragraphs the authors have attempted to show that *Veromessor* is a derivative of *Messor*. It must be admitted, however, that in the last analysis this derivation is based upon probabilities rather than facts.

If we compare a worker of *pergandei* with one of equal size belonging to *Messor barbarus* their striking similarity is obvious. Indeed, if in this comparison we select the subspecies *aegypticus*, the point for point resemblance of the two forms is astonishing. While it is true that the worker of *pergandei* has eyes of a different shape, somewhat

sharper epinotal spines, feebler thoracic sculpture, more numerous hairs, and a deeper color, all of these differences, except perhaps the first, are within the latitude allowed for subspecific or varietal aberrations. One can scarcely avoid speculation as to the status which would have been accorded to *pergandei* had it chanced to occur in the Mediterranean basin instead of the southwestern United States. Additional parallelism is evident in the ecological stations and habits of the two genera.

A consideration of the distribution of the genus *Messor* shows that it occurs in the greatest abundance in those portions of Africa and Asia Minor which border the Mediterranean. A branch follows up the valley of the Nile, swinging across central Africa, and extending southward to the Cape of Good Hope. Another gets into the Balkans and southern Russia. Still another passes across Turkestan and northern India into China. Since the climatic conditions throughout this enormous area vary widely, it is difficult to make any satisfactory generalization concerning the relationship of *Messor* to climate. However, one may safely assert that wherever it occurs the genus *Messor*, with the exception of the East Asian species *aciculatus*, shows a marked preference for high temperatures and aridity. This is well shown by the studies of Doflein (6), who observed the activities of these insects in Macedonia where he found the workers of *M. barbarus* actively foraging during the hottest hours of the day in the months of July and August. At that time the heat was sufficiently intense to drive the workers of the other species to the shelter of their nests. Despite its marked thermophily there is apparently an upper temperature limit for *barbarus*. According to Escherich, who observed this insect in Erytrea, it is crepuscular and nocturnal in habit. Needless to say this does not negate the thermophily of *barbarus*, since its presence in the parched deserts along the Red Sea indicates a strong preference for high temperature. This preference or tolerance can only mean that *barbarus* is well adapted to desert life, a conclusion further borne out by its seed-storing habit and the well-developed psammophore in most of the forms. There is every reason to believe that *barbarus* is a xerophile of long standing. Since it is definitely adapted to excessive temperatures, it seems surprising that in Asia proper it avoids the great desert of western India. The relatively few records of this insect from India all come from the northwestern Himalayas. From this point eastward there are virtually no records of the genus until one reaches eastern China where *aciculatus* occurs.

There can be little doubt that this break is occasioned by inadequate field work rather than the absence of the genus, since the area traversed is in the almost unknown region of eastern Turkestan and Tibet. *M. aciculatus*, the most eastern representative of the genus Messor, shows a number of differences when contrasted with *barbarus*. The most obvious of these is structural since *aciculatus* possesses monomorphic workers and hence may be considered to be less specialized than *barbarus*. While very little has been published on the ethology of *aciculatus*, the available data seem to show that it is unquestionably less xerophilous than the circummediterranean species. It usually nests in areas which are capable of cultivation, apparently preferring these to desert conditions. Its known range extends from Foochow north to Peking. In terms of latitude this represents a north to south distribution from Lat. 40° to Lat. 25°, which is almost identical with the Mediterranean portion of the range of *barbarus*. It must be borne in mind, however, that the climatic conditions in eastern China are influenced by the Kamchatka Current and that, for this reason, the area in which *aciculatus* occurs shows a lower average yearly temperature than the corresponding portion of the range of *barbarus*. That *aciculatus* should be less thermophilous and less xerophilous than the other species of Messor appears to the authors to be a fact of considerable significance.

Let us now turn our attention to the genus *Veromessor*. In the sun-baked deserts of western Arizona and southern California we find *V. pergandei*. In these areas the midday temperatures during the summer months usually run in the neighborhood of 116° F., and temperatures of 130° are not unknown. Despite the terrific heat and glare of the sun, *pergandei* workers forage actively in the middle of the day during the greater part of the summer. It is perhaps too much to say that they are never affected by the heat, but it is true that they are kept in the nest only by temperatures of unusual intensity. Like *M. barbarus*, *pergandei* collects and stores seeds and has a beautifully developed psammophore. We must, therefore, regard it as a highly xerophilous species which has probably existed in the deserts over a very long period.

Adjacent to the extreme western part of the range of *pergandei* we find another species, *V. andrei*. Its known range extends from San Diego almost to the Oregon border. In the southern portions of this range the climatic conditions are, of course, often hot and arid. However, since *andrei* prefers the western slopes of the Coast Range,

where the winds from the Pacific mitigate both temperature and dryness, even the extreme southern portions of its range are less hot and arid than the areas in which *pergandei* occurs. As for the portion of the range of *andrei* which lies in northern California little need be said. Whatever zonal interpretation may be placed upon the valleys lying between the mountains of the Coast Range, it is certain that their mean yearly temperature is notably lower and their precipitation much higher than in the great Sonoran areas farther to the south. One may, therefore, question whether *andrei* is a very xerophilous species, and, if it is included in such a category, it is necessary to make strong qualifications concerning its response to temperature and moisture. Moreover, *andrei* further differs from *pergandei* in the character of the worker caste. The workers of *andrei* are monomorphic or very feebly polymorphic and for this reason it must be considered less specialized than *pergandei*.

To summarize the data just presented one may state that in both Messor and Novomessor we find the more specialized species completely xerophilous and living in areas of unusually high temperature. Each genus, however, contains a less specialized form which is less xerophilous and whose range lies in an area of lower temperature.

As has already been stated, the facts just presented are open to several explanations. Since the two genera are separated by the enormous territory which extends from northern China through Siberia and Alaska into Canada and the northwestern United States, one may defend the view that they have nothing in common and that the similarities just discussed are cases of convergence without phylogenetic significance. On the other hand, it must be borne in mind that the area which now separates the two is one of the few great intercontinental migrational pathways whose existence has never been disputed. The statement that in past periods the genus Messor might have utilized the Siberian-Alaskan land bridge certainly offers no novelty when compared with our customary beliefs on migration in this area. In view of the marked xerophily and thermophily of some of the forms in each genus our hypothesis necessitates a very different climate for Siberia and Alaska if Messor has ever been present in those areas. There is no reason why this may not have been true, since there is ample evidence to show that at several periods prior to the Pleistocene the climate of the Northern hemisphere was tropical or subtropical in character. We assume that during one of these periods of warmth the range of the genus Messor extended through north-

eastern Asia and northwestern North America. The subsequent isolation of the North American representatives of this original stock through climatic change has resulted in the development of the separate characters which mark the present genus *Veromessor*.

This assumption would be considerably strengthened by paleontological evidence of the genus *Messor* in the New World. Dr. Carpenter, in his interesting monograph of the fossil ants of North America, (7) records *Messor sculpturatus* from the Florissant shales. This insect, described from female specimens, was placed in the genus *Messor* because the fore wing has two cubital cells. Dr. Carpenter assumed, therefore, that it cannot be included in the genera *Novomessor* or *Veromessor*.

Through the courtesy of Dr. Carpenter, the junior author has examined the holotype and several other specimens of *M. sculpturatus*. As Dr. Carpenter has noted in his original description, the holotype is rather faint. Nevertheless certain details of the sculpture have been clearly preserved. Thus it may be seen that the antennal scapes and the abdomen are striate. Not all the abdominal striae have been preserved but those which are present appear as beautifully regular, fine, parallel lines. Unfortunately similar conditions of sculpture do not occur in the present day species of the genus *Messor* and, more unfortunately still, they do occur in some of the South American species of *Pogonomyrmex*. Although it would be extremely gratifying to have paleontological proof of the presence of *Messor* in North America, there seems to be more reason for regarding Dr. Carpenter's *sculpturatus* as a *Pogonomyrmex*. For the present, therefore, we have no conclusive proof of the origin of the genus *Veromessor*. The following key presents characters by which the workers of the various forms may be recognized:

Key to the genus Veromessor.

1. Head coarsely reticulo-rugose or with wavy longitudinal rugae, the interrugal spaces coriaceous or granulose.....6
 - Head covered with fine, longitudinal striae which are interrupted by punctures.....2
2. Epinotal spines short, their length not exceeding the distance separating their bases.....3
 - Epinotal spines long, their length twice as great as the distance separating their bases.....4

3. Dorsum of the pronotum without sculpture, shagreened, and strongly shining, color black or piceous brown. *pergandei*
Dorsum of the pronotum longitudinally striate, feebly shining, color reddish brown. *stoddardi*
4. Dorsum of the thorax not impressed at the mesoëpinotal suture, thorax blackish red, abdomen piceous black. *julianus*
Dorsum of the thorax strongly impressed at the mesoëpinotal suture, thorax reddish yellow, abdomen brown with a yellow spot at the base of the first segment. 5
5. Hairs on the abdomen numerous and regular in arrangement, length of insect 6.5 mm. *julianus* subsp. *clarior*
Hairs of the abdomen sparse and irregular in arrangement, length of insect 4.5 mm. *julianus* subsp. *manni*
6. Head coarsely reticulo-rugose, the first gastric segment strongly granulose and completely opaque. 7
Head with wavy longitudinal rugae, the entire gaster strongly shining at most microscopically shagreened. 8
7. Basal face of the epinotum in profile straight or very feebly and evenly convex, epinotal spines slightly curved downwards. . . . *relictus*
Basal face of the epinotum in profile more strongly convex, with a pronounced median impression, epinotal spines straight. *relictus* subsp. *epinotalis*
8. Rugae along the midline of the head fine, approximately straight and not diverging behind; the interrugal spaces over the entire head strongly coriaceous, dull. *lobognathus*
Rugae along the midline of the head coarse, wavy and diverging behind; the interrugal spaces granulose and feebly shining. 9
9. Proximal portion of the antennal scape ending in a trumpet-like expansion; head longer than broad. 10
Proximal portion of the antennal scape ending in a flattened, spatulate area; head as broad as long. *chamberlini*
10. Antennal scapes in repose just reaching the occipital border; color blackish red to clear red. *andrei*
Antennal scapes in repose slightly surpassing the occipital border, color castaneous or flavous. 11
11. Color castaneous brown; sculpture of head and thorax strong, shining. *andrei* subsp. *castaneus*
Color flavous yellow; sculpture of head and thorax rather feeble and dull. *andrei* subsp. *flavus*

Veromessor andrei (Mayr.)

Veromessor andrei (Mayr), Verh. Zool-bot. Ges. Wien, Vol. 36, p. 443, 448 (1886) (*Aphaenogaster*) ♂.

Stenamma (*Messor*) *andrei* Emery, Zool. Jahrb. Syst. Vol. 8, p. 306 (1895) ♀.

Worker: Length: 4.5–7 mm. (Plate II, fig. 2.)

Head, exclusive of the mandibles, four-fifths as broad as long, slightly wider behind the eyes than in front of them, the sides in front of the eyes straight, behind the eyes slightly convex and meeting the occiput in a broadly rounded angle. Occipital border with a broad though very shallow median concavity. Border of the clypeus straight or at most very feebly convex, the median portion feebly sulcate, the lateral portions raised into a narrow ridge or welt which bounds the anterior edge of the antennal fossa. Frontal area opaque. Frontal carinae very narrow and welt-like, slightly divergent above the insertion of the scapes, much more divergent posteriorly where they fuse with the sculpture of the head at a point just behind the posterior border of the antennal fossae. Eyes of moderate size, oval in outline, strongly convex, with about sixteen facets in their greatest diameter, their posterior border lying at a point half way between the insertion of the mandible and the occipital border. Antennal scapes slender, the proximal portion dilated to form a trumpet-shaped expansion, distal to this the median portion of the scape somewhat constricted, the apical end only slightly swollen and no larger in diameter than the flared proximal end. When in repose the tip of the scape just reaches the occipital border. Funicular joints, with the exception of the last three, all longer than broad, especially the first joint, which is more than twice as long as broad; joints ten and eleven only slightly longer than broad and notably thicker than the preceding joints, the terminal joint bluntly pointed, longer but no thicker than the preceding two. Mandibles large and stout with the evenly curved outer edge meeting the masticatory margin in a powerful two-cusped terminal tooth. The remaining six or seven teeth much smaller, forming a concave serrated edge to the masticatory margin, the latter meeting the straight inner margin of the mandible at a right angle.

Thorax, seen in profile, with a gibbous promesonotum, the promesonotal suture marked by a somewhat flattened area but not forming a distinct depression; epinotum greatly depressed, the mesoepinotal suture broad and strongly impressed; basal face of the epinotum virtually flat, sloping slightly backward, terminating in two

large, straight, divergent spines, which slightly exceed the length of the basal face of the epinotum; declivous face of the epinotum short and concave. Seen from above, the promesonotum is pyriform and notably wider than the rest of the thorax, the sides of the thorax very slightly constricted at the mesoëpinotal suture, sides of the epinotum virtually parallel. First joint of the petiole with a rather thick peduncle, which gradually increases in thickness from its anterior end to the base of the node, its ventral surface with a sharp anterior tooth and a low, rounded lamella at its midpoint. Node of the petiole small, its height no greater than the thickness of the peduncle, its anterior face forming a continuous feebly concave slope with the dorsum of the peduncle, the summit acute, the posterior face very declivous and strongly convex, posterior peduncle extremely short. Postpetiole in profile lower than the petiole, the node low and rounded above, with the anterior face longer though less declivous than the posterior face, ventral surface with a prominent V-shaped median impression. Seen from above, the rather narrow petiole is scarcely two-thirds as wide as the campanulate postpetiole. Gaster large. Legs long, the femora slightly swollen.

Head subopaque, completely covered with rather coarse, wavy rugae which diverge toward the occiput. The interrugal spaces finely granulose and feebly shining. Mandibles shining, with moderately prominent longitudinal striae. Antennal scapes feebly granulose, more shining than the head. Thorax somewhat more opaque than the head, completely covered with irregular rugae, except at the front and lateral edges of the pronotum where they are subparallel. Petiole and postpetiole strongly granulose, with a few short rugae. Gaster smooth and shining, with numerous fine piligerous punctures.

Entire insect covered with glistening whitish hairs which are very unequal in length; the gular hairs forming rather poorly developed ammochaetae, longer than the majority of hairs on the head and thorax but almost equalled in length by a few long hairs which occur on the upper surface of the head, the pronotum, and the coxae of the fore legs. Dorsum of the first gastric segment entirely covered with hairs which are relatively short and more nearly of equal length than those on the head and thorax. Hairs on the remaining abdominal segments confined to the posterior border of each segment. Antennal scapes, femora, and tibiae with numerous, short, erect hairs; those on the tarsi somewhat finer and subappressed; funicular hairs very fine, short, and subappressed, except on the last four joints where they are replaced by golden pubescence.

Color variable. In some specimens the entire insect is reddish black, except for the nodes of the petiole which are reddish. In other specimens only the posterior part of the gaster is black, the first gastric segment castaneous and the remainder of the insect clear, deep red. Not infrequently both the head and gaster are infuscated, leaving only the thorax and nodes of the petiole red.

In his original description Mayr merely notes that the types came from California. We have seen material from the following localities:

California: Antelope, Sacramento Valley. (C. D. Cook.)
Berkeley. (W. M. Wheeler.)
Claremont. (C. F. Baker.)
Descanso. (No collector.)
Edendale. (J. C. Bradley.)
Eldridge. (J. A. Kusche.)
Laguna Beach. (E. O. Essig.)
La Jolla. (W. M. Wheeler.)
Palo Alto. (H. Heath and Miss Isabel McCracken.)
Perris. (J. C. Bradley.)
Point Loma. (W. M. Wheeler.)
Ramona. (J. C. Bradley.)
Riverside. (H. L. Quayle.)
Santa Catalina Island. (C. F. Baker.)
San Diego. (W. M. Wheeler.)
Santa Isabel. (No collector.)
San Isidro. (W. M. Wheeler.)
San Jacinto. (No collector.)
Tejon Pass. (W. M. Wheeler.)
Weaverville. (W. S. Creighton.)
Whittier. (J. C. Bradley.)
Nevada: Ormsby. (C. F. Baker.)
Mexico: Coronado Island. (C. T. Brues.)

As may be seen from the locality records just presented, the known range of *andrei* lies almost entirely in California but, since it has been taken as far north as Weaverville, there is good reason to suppose that it also occurs in Oregon. On the other hand, while it must certainly occur in continental Mexico, it is doubtful whether its range extends much below the southern boundary of California, since it has never been taken by collectors in Lower California. It is apparently replaced in this area by *julianus*. As has already been

mentioned, *andrei* nests in the foot hills of the Coast Range. Although built in open areas the nests are not particularly conspicuous. There is usually no crater, but the nest entrance is surrounded by an area of gravel which, because of its irregularity, can hardly be called a disc. The workers forage in files and collect seeds which are apparently stored in the nest, to judge from the chaff which surrounds the nest entrance. This chaff is scattered about and not formed into a crescent or ring as in the case of *pergandei*.

Very little is known of the mating habits of *andrei*. Sexual forms which we have examined have been collected from June to September 15. In view of the occurrence of the species in the northern part of California, it seems likely that the marriage flight takes place early in the spring.

The color variations which occur in *andrei* are very perplexing. While it cannot be denied that it is possible to select specimens which show a very pronounced difference in color, the junior author is convinced that these variations are not suitable for varietal separation. Their inconstancy within the colony is such that there can be little doubt that they are merely nest varieties. Nevertheless, there appears to be a certain amount of correlation between the color of the insect and its geographical distribution. In general it is true that colonies from the more southern localities show a predominance of red individuals, while those from the north tend more to blackness. Additional field observations are needed in this case to determine whether the development of melanism in *andrei* is the result of low temperature or relatively moist nest sites.

Unlike the variants just discussed, the color of the two subspecies *castaneus* and *flavus*, described below, is quite constant. Moreover, these new forms show regular and significant structural differences which clearly separate them from the typical *andrei*.

***Veromessor andrei* subsp. *castaneus* subsp. nov.**

The most obvious difference between *castaneus* and the typical *andrei* lies in the lighter color of the new subspecies. The entire insect is a uniform castaneous brown with the abdomen no darker (in some specimens lighter) than the head and thorax. The structural differences which distinguish *castaneus*, while less apparent, are of more significance. It is less polymorphic, the largest workers measuring only 5.2 mm. (7 mm. in the typical *andrei*). The antennal scapes are longer, slightly surpassing the occipital border. The tooth and

lamella on the ventral surface of the peduncle of the petiole are much reduced and in some cases lacking entirely, so that the ventral surface of the petiole appears merely sinuate. The epinotal suture is less deeply impressed. In sculpture the subspecies *castaneus* is very similar to the typical *andrei*, although the body hairs are perhaps a little finer and a trifle less numerous.

Described from a large series of workers collected by the senior author at Jacumba and San Diego, Southern California. Jacumba may be regarded as the type locality.

***Veromessor andrei* subsp. *flavus* subsp. nov.**

The color of this form, as the name implies, is yellow. In addition, it differs from the typical *andrei* in a number of structural characters. The head is noticeably narrower, particularly in the posterior half, where the sides are somewhat convergent toward the occiput. The latter is practically flat. The antennal scapes are longer and slightly surpass the occipital border, as in the subspecies *castaneus*. The node of the petiole is smaller and noticeably narrower. The sculpture is more feeble, particularly on the thorax, and the entire insect is less shining.

The types were collected by the senior author on Aug. 17, 1917, at Jacumba, Southern California.

***Veromessor chamberlini* (Wheeler).**

Veromessor chamberlini, Wheeler, Bull. Amer. Mus. Nat. Hist. Vol. 34, p. 410 (1915) ♀ (*Messor*).

Worker: Length 4 mm. (Plate II, fig. 5.)

Head, exclusive of the mandibles, as broad as long, the sides very slightly narrowed from a point just posterior to the eyes to the insertion of the mandibles. Occiput flat, its angles very broadly rounded. Anterior border of the clypeus virtually straight, the median lobe very shallowly impressed in front and with two feeble carinae. Mandibles large, their external border strongly curved; masticatory margin with two sharp, prominent, terminal teeth and a row of denticles along the rest of the margin. Frontal carinae prominent, moderately divergent anteriorly and strongly divergent behind. The antennal scapes in repose fail to reach the occipital border by a distance less than their greatest thickness; the proximal end of the scape flattened and forming a spatulate portion which is wider than the feebly clavate tip. First funicular joint slightly shorter than the

following two together; funicular joints 2-7 all longer than broad though gradually increasing in thickness, the remaining four joints much more thickened and forming a distinct club. Eyes rather small, feebly convex, suboval, situated at the middle of the side of the head.

Promesonotum in profile strongly though somewhat irregularly convex, with the mesonotum descending abruptly to the much lower epinotum, the mesoëpinal suture feebly impressed. Dorsum of the epinotum very feebly sinuate and much longer than the declivous face, the angle between them armed with two long, feebly arcuate spines which are thin toward the tips but rather thick toward the base. Seen from above, the promesonotum is subpyriform and notably wider than the remainder of the thorax, with the promesonotal suture obsolescent but rather clearly visible in certain lights. Sides of the thorax not constricted at the mesoëpinal suture, the epinotal spines only moderately divergent and approximately as long as the distance between their tips. Petiole in profile with a long anterior peduncle, which lacks a ventral tooth and increases slightly in diameter toward the node. The sloping anterior face of the node meets the peduncle in a very wide angle, the summit of the node is rounded, the posterior face short and abrupt. The posterior peduncle is short and forms a distinct angle at its junction with the node. Postpetiole in profile with a bluntly angular dorsum and a sinuate ventral face. Seen from above the peduncle of the petiole is compressed anteriorly by two semicircular constrictions, posterior to which it gradually increases in width. Postpetiole from above subpyriform only slightly less than twice as wide as the node of the petiole. Gaster small, oval.

Head entirely covered with fine rugae which diverge from the median line toward the occipital angles; interrugal spaces feebly granulose and somewhat shining. Mandibles with coarse longitudinal striae, feebly shining. Clypeus granulose, opaque except for the median lobe which is rather strongly shining. Frontal area opaque. Antennal scapes smooth, strongly shining. Thorax, except for the pronotum where the rugae are transversely arcuate, entirely covered with strong irregular longitudinal rugae, somewhat more shining than the head. Petiolar nodes very feebly granulose, somewhat shining. Gaster very smooth and shining, the small piligerous punctures scarcely visible. Hairs very irregular both in length and thickness. Gular ammochaetae very poorly developed, consisting of only a few, fine, long hairs. Clypeus with a fringe of rather stout, golden hairs of

irregular length. Front, vertex, and occiput with a number of short, fine, whitish hairs many of which are suberect. Thoracic hairs abundant over the entire dorsum and very irregular in length. Petiole, postpetiole, and gaster with abundant whitish hairs which are more uniform in length than those of the thorax. Femora with a few short erect hairs, those of the tibiae, tarsi, and antennal scapes finer, more numerous, and suberect.

Head and thorax clear, ferruginous red, nodes of the pedicel a duller red, base of the gaster yellowish red, femora, tibiae, and posterior gastric segments piceous brown.

Redescribed from the type series in the collection of the senior author. This consists of a number of workers taken by R. V. Chamberlin on Santa Cruz Island, California. The species is apparently known only from type material. Sexual forms unknown.

Superficially *chamberlini* resembles a small worker of *andrei* but it may be easily distinguished from that species by the flattened base of the antennal scape, broader head, shorter epinotal spines, uniformly feebler sculpture, and notably sparser pilosity.

***Veromessor julianus* (Pergande).**

Veromessor julianus (Pergande), Proc. Calif. Acad. Sci. (2) Vol. 4, p. 164, (1894) (*Aphaenogaster*).

Worker: Length 5–8 mm. (Plate II, fig. 7.)

Head in the largest workers subquadrate, the length from the flat occipital border to the anterior margin of the clypeus very slightly exceeding the greatest width. Head widest just behind the eyes, the width slightly decreasing from that point to the insertion of the mandibles, sides straight or very slightly convex. In the smaller workers the head is somewhat more narrow, widest at the eyes, with the sides feebly convex and the occipital angles more broadly rounded, which gives the occipital border a slightly convex appearance. Clypeus short, scarcely projecting, the anterior edge with an irregular median impression, the median lobe not clearly marked off, the entire middle portion of the clypeus longitudinally striate. Frontal carinae narrow and rather short, feebly divergent in front, their lateral margins only moderately divergent behind and fusing with the head at a point on a level with the frontal area; the latter moderately depressed and subopaque. Mandibles powerful, their exterior margin strongly and evenly curved; teeth poorly developed, the apical two much rounded and forming a terminal lobe at the junction of the

outer and masticatory margins, the remainder of the masticatory margin serrate rather than toothed. Eyes oval, moderately convex, surrounded by a shallow and narrow groove. Antennal scapes straight and slender, the tips not noticeably swollen, the entire scape gradually increasing in diameter from base to apex. In repose the scape surpasses the occipital border by a distance slightly in excess of its greatest thickness. Funicular joints all notably broader than long, joints 2-6 of approximately the same diameter, the remaining joints increasing in thickness and forming a poorly developed terminal club.

Promesonotum seen from above subpentagonal, with the anterior border strongly convex, the two lateral and posterior borders more nearly straight. Promesonotal suture obsolete. Epinotum from above notably narrower than the pronotum, rectangular in outline, the sides not constricted at the mesoëpinotal suture. Spines strongly divergent, straight, the apical two-thirds rather thin, the basal third decidedly thickened; length from base to apex slightly less than the distance between their tips. Seen in profile, the dorsum of the pronotum is feebly convex, that of the mesonotum virtually straight and sharply sloping, the epinotum much depressed, with straight basal and declivous faces which meet at a sharp angle. Declivous face of the epinotum approximately two-thirds as long as the basal face, the spines at their junction only slightly elevated, forming an angle of about twenty degrees with the plane of the basal face. Mesoëpinotal suture not impressed.

Petiole in profile with a long, thick, tapering anterior peduncle which has neither ventral tooth nor lamella. Anterior face of the node sloping forward to form a broad angle with the dorsum of the peduncle. Posterior face of the node strongly convex, meeting the anterior face in a sharp angle at the summit of the node. Posterior peduncle very short. Postpetiole in profile with a rather long and narrow anterior peduncle, the node low, feebly convex above, its posterior face not constricted into a posterior peduncle but broadly applied to the first gastric segment. Seen from above, the petiole is narrow, bluntly cuneate in outline, with the broadest portion at the base of the node. Postpetiole trapezoidal, much narrowed in front and not at all constricted where it joins the gaster, which is large and oval.

Head shining, entirely covered with fine and rather even striae which are interrupted at intervals by small, shallow punctures. The striae on the front diverge from the midline toward the occipital

angles where they are met by longitudinal striae which extend from the insertion of the mandibles to the occipital angles. Mandibles shining, with coarse longitudinal striae. Clypeus somewhat duller, the striae more irregular. Thorax subopaque, the pronotum with close-set, transverse rugae, those on the mesonotum and epinotum more widely separated and irregular. The interrugal spaces densely granulose over the entire thorax, especially on the sides of the pronotum where the granulation largely replaces the rugae. Lower portions of the petiole and postpetiole opaque, very finely granulose, the summits of the nodes, especially the postpetiole, shining. Gaster shining, feebly shagreened, with very small piligerous punctures.

Hairs rather sparse. Gular ammochaetae consisting of about half a dozen long curved hairs on either side of the head. Anterior border of the clypeus with a few long hairs, the remaining hairs on head and thorax all shorter and very uneven in length. Abdominal hairs short and more nearly uniform in length. Femora, tibiae, and tarsi covered with numerous fine erect hairs. Those of the scapes and funiculi very fine but erect or suberect, except on the terminal funicular joints where they grade into pubescence.

Head dingy blackish red, the thorax somewhat clearer red, petiolar nodes and gaster piceous brown. Mandibles, antennae, and legs yellowish brown.

Redescribed from types taken by Pergande at San Julio, Lower California. The sexual forms of this species are unknown and the workers themselves appear to be represented only by the type material. Additional specimens examined by the authors do not belong to the typical *julianus* but to the two variants described below.

***Veromessor julianus* subsp. *clarior* subsp. nov.**

This form differs from the typical *julianus* in the following characteristics:

The head is more nearly quadrate, being almost exactly as long as broad; the antennal scapes are shorter, their tips in repose just reaching the occipital border; the dorsum of the thorax is notably impressed at the mesoëpinotal suture; the epinotal spines are longer and thinner and decidedly more elevated, meeting the plane of the basal face of the epinotum at a forty-five degree angle; the cephalic striae are finer and the granulation of the thorax is much less pronounced. The insect is much more hairy than the typical *julianus*, this difference being especially noticeable in the case of the gular ammochaetae and

the abdominal hairs. The color is a clear, yellowish red, the gaster piceous brown, usually with a yellowish spot at the base of the first segment.

Described from a series of workers taken by H. C. Millender at Comundu, Lower California. Additional specimens agreeing in every particular were taken by Dr. W. M. Mann at Loreto, Lower California.

Veromessor julianus subsp. **manni** subsp. nov.

In this form the dorsum of the thorax is impressed at the meso-epinotal suture, as in the subspecies *clarior*. It differs from *clarior*, however, in its smoother cephalic sculpture, the striae in the smaller specimens being scarcely visible. Furthermore, the epinotal spines are shorter, approaching the condition found in the typical *julianus*. The color of the subspecies is less clear than that of *clarior*, the head especially tending toward a muddy, brownish red. The yellowish spot at the base of the first gastric segment, which appears to be a fairly constant character in *clarior*, is reduced in size or absent altogether in *manni*. In addition this subspecies appears to be smaller than either *clarior* or the typical *julianus*. This distinction must, however, be used with caution since the type series consists of few specimens and it is entirely probable that the examination of additional material will prove this statement to be erroneous. The length of the specimens examined varies from 4.5 mm. to 6 mm.

Described from five specimens taken by Dr. W. M. Mann at Purissima, Lower California.

Veromessor lobognathus (Andrews).

Veromessor lobognathus (Andrews), Psyche, Vol. 23, No. 3, p. 81 (1916) (*Messor*).

Worker: Length 6 mm. (Plate II, fig. 6.)

Head subquadrate, as broad as long (mandibles excluded), the sides approximately straight, a trifle narrower in front of the eyes than behind them. Occiput flat, with the occipital angles broadly and evenly rounded. Anterior margin of the very short clypeus straight, with a shallow V-shaped median impression. Eyes oval, moderately large and feebly convex, placed at the middle of the sides of the head. Mandibles large and strongly convex in two planes, so that the lobed tip of the masticatory margin is carried back beneath the mandible and is not noticeable unless viewed from a point in front of the lower margin. This lobe, which appears to consist of three fused teeth,

is sharply set off from the remainder of the masticatory margin. Frontal carinae subparallel, rather thick and short, with a welt-like portion which extends from the anterior end encircling the front of the antennal fossa. Antennal scapes in repose surpassing the occipital border by an amount slightly in excess of their greatest thickness, the basal end of the scape flattened and strongly spatulate. Distal to the flattened portion the diameter of the scape gradually increases toward the slightly swollen tip. First and last funicular joints of equal length, the remaining joints all much shorter; the diameter of the funicular joints gradually increases distally, so that no distinct club is formed although the apical are almost twice as thick as the basal joints.

Dorsum of promesonotum, seen in profile, evenly and moderately convex; the mesoëpinal suture with a broad, flattened impression whose posterior boundary is marked by a slight ridge on the basal face of the epinotum. Basal face of the epinotum flat and feebly sloping, forming a sharp angle with the shorter declivous face, their angle armed with two spines of moderate length. Seen from above, the promesonotum is pyriform and notably broader than the remainder of the thorax; the mesoëpinal suture forms a narrow slotlike groove between the mesonotum and epinotum without constriction of the sides in that area. Epinotal spines feebly divergent and very slightly incurved, their length slightly more than half the distance between their tips.

Petiole, seen in profile, with a thick anterior peduncle whose dorsum forms a continuous slope with the anterior face of the node. Lower surface of the peduncle with a small anterior tooth. Node of the petiole small and low with a flattened summit, which slopes backwards to the short posterior face. Posterior peduncle short and very thick. Postpetiole in profile with a feebly convex dorsum and a well-marked impression in the middle of the ventral surface, the posterior portion slightly constricted at its junction with the gaster. Seen from above, the sides of the petiole are parallel as far forward as the two rather prominent spiracles, anterior to which the peduncle is much narrowed by a semicircular impression at either side. Postpetiole almost twice as wide as the petiole, subtriangular. Gaster rather large, oval. Legs long, the femora somewhat incrassated.

Mandibles shining, with rather coarse but shallow longitudinal striae. Clypeus granulose, subopaque. Frontal area shining. Head opaque, completely covered with fine longitudinal rugae, the interrugal

spaces coriaceous. Rugae along the median portion of the head not divergent, the lateral rugae encircling the eye. Antennal scapes finely granulose, feebly shining. Thorax slightly shining, the rugae with which it is completely covered more irregular and coarser than those of the head. Petiole and postpetiole finely granulose, opaque. Gaster and legs shining.

Hairs moderately abundant, stout, erect, and golden. Gular ammochaetae moderately developed, the inner row of long curved hairs flanked at the side by additional hairs which are shorter and less regularly placed. Inner surface of the mandibles with numerous long hairs, those on the outer surface short, fine, and suberect. Clypeus with a fringe of long curved hairs. Except for two or three long hairs on the front, the remainder of the head is covered with short, stout, and rather blunt hairs of fairly uniform length. Hairs on the pronotum about equal in length and abundance to those on the occiput. Hairs on the epinotum much sparser. Petiole with a tuft of very coarse hairs arising from the posterior face of the node. Dorsum of the postpetiole with numerous coarse, long hairs; those of its lower surface, shorter, sparser, and much finer. Hairs on the gaster relatively sparse, uniformly distributed over the first segment; over the rest of the gaster confined to an irregular row at the posterior edge of the segment. Femora with sparse, short, erect hairs; those of the tibiae, tarsi, and antennal scapes shorter, much more numerous, and suberect. Hairs on the funiculi very fine, grading into pubescence toward the tips.

Color clear orange yellow, the posterior gastric segments, except the terminal segment, which bears a castaneous band, somewhat lighter than the remainder of the body. Clypeus and mandibles tinged with brown, the masticatory margin of the mandibles piceous.

Redescribed from a single cotype in the collection of the senior author. *Lobognathus* is apparently known only from the four cotype specimens taken by T. D. A. Cockerell at Glenwood Springs, Colorado.

In her original description of *lobognathus* Miss Andrews stressed the apical mandibular lobe and the spatulate base of the scape as the outstanding peculiarities of this species. In point of fact, *lobognathus* is not unique in either respect, since a similar, though smaller, mandibular lobe occurs in *julianus*, and *chamberlini* possesses a scape with a spatulate base. By far the most outstanding characteristic of *lobognathus* is its extraordinary resemblance to *Pogonomyrmex occidentalis* in sculpture and pilosity. The dull, strongly coriaceous head

with its broad band of circumocular rugae is startlingly similar to that of *occidentalis*. The similarity is further increased by the unusual hairs of *lobognathus*, which are coarse, blunt, and of rather uniform length. Since the hairs in the other species of *Veromessor* tend to be slender, pointed, and very irregular in length, this difference is all the more surprising. It must be borne in mind, however, that these similarities are superficial and cannot be of phylogenetic significance. In its more fundamental characters, the structure of the thorax, petiolar nodes, clypeus, and frontal lobes, *lobognathus* plainly shows itself to be a true *Veromessor*. Its superficial resemblance to *P. occidentalis* may be explained either as convergence due to similarity of habits and environment or perhaps as mimicry. Certainly the characteristics of *occidentalis* should make it an excellent model since it is by far the most pugnacious and fiercely stinging ant in the area in which *lobognathus* occurs.

It is to be regretted that so little is known of the distribution of *lobognathus*. Its occurrence in the western foothills of the Rockies offers an interesting parallel to that of *andrei* in the Coast Range of California.

***Veromessor pergandei* (Mayr).**

V. pergandei Mayr, Verh. Zool-bot Ges. Wien, Vol. 36, p. 448-449 (1886). (Aphaenogaster).

Worker major: Length 6 mm. (Plate II, fig. 3).

Head, exclusive of the mandibles, as broad as long, widest just behind the eyes and narrowing from this point to the insertion of the mandibles. Anterior to the eye the side of the head is straight, posterior to the eye it is convex, passing through a broadly rounded angle to the straight occipital border. Clypeus scarcely projecting, its anterior edge feebly arcuate, the median lobe with a prominent, blunt central tooth from which several well-marked rugae extend rearward between the antennal lobes. Antennal lobes parallel, not spreading laterally in the rear, the frontal area between them sub-circular and opaque. The lateral border of the clypeus and the anterior border of the side of the head together form a very distinct semi-circular impression at the base of the mandible. Mandibles massive, their outer border strongly and evenly convex, the masticatory margin feebly concave, armed with two stout teeth at its junction with the outer border and a single smaller tooth at the junction with the inner border, the remainder of the masticatory margin feebly denticulate or smooth. Antennal scapes slender, their tips in repose just reaching

the occipital border. Funicular joints all of approximately the same length and all longer than broad, their diameter gradually increasing apically. The eyes, which are set at the middle of the sides of the head, are large and elongate, with the convex upper orbit meeting the straight lower orbit in a bluntly rounded anterior angle.

Promesonotum, seen from above, subpyriform, the promesonotal suture obsolete above, but its position indicated laterally by a broad impression. Mesoëpinotal suture with a broad and fairly deep impression. Epinotum subtriangular, slightly longer than broad but not as long as the promesonotum, armed posteriorly with a pair of feebly divergent, short, slender spines. Seen in profile, the promesonotum is strongly gibbous and descends to the much lower epinotum through an even curve, except at the point adjacent to the mesoëpinotal suture where the dorsal impression of the thorax gives it a short, steep posterior face. Dorsum of the epinotum in profile straight, except for a low anterior ridge which bounds the rear edge of the mesoëpinotal impression. Epinotal spines short, only slightly elevated, and arming the sharp angle between the basal and declivous faces of the epinotum.

Anterior peduncle of the petiole, seen in profile, thick, its upper face meeting the anterior face of the node in such a wide angle that the two form what is virtually a single slightly concave slope. Lower surface of the peduncle straight or very feebly sinuate, with a small angular tooth at its anterior end. Posterior peduncle very short and thick. Node of the petiole small, its height not equal to the greatest thickness of the anterior peduncle, the summit flattened and sloping rearward to the very short posterior face. Postpetiole in profile lower than the node of the petiole, with its upper surface consisting of a strongly sloping anterior face and a somewhat less sloping posterior face, which meet at the summit in a broadly rounded angle. Ventral face of the postpetiole sinuate. Seen from above, the node of the petiole is scarcely wider than the peduncle and only slightly more than half as wide as the trapezoidal postpetiole. Gaster oval, its anterior edge slightly flattened at either side of its attachment to the postpetiole.

The entire insect shining. Mandibles with numerous coarse longitudinal striae. Head with numerous, small piligerous punctures. Sides of front behind the clypeus with feeble longitudinal striae which extend rearward to the middle of the head. Antennal lobes with similar striae which spread fanwise on the front, disappearing at the

level of the posterior edge of the eyes. The remainder of the head may be highly glabrous or more or less covered with coarse shagreening, heavy enough partially to obliterate the shining character of the surface. Pronotum feebly shagreened, moderately shining. Mesonotum, epinotum, and petiolar nodes finely granulate and feebly shining. Gaster very smooth and shining, with moderately numerous, small, piligerous punctures.

Hairs whitish or yellowish, slender but with rather blunt tips. Those on the under surface of the head and the lower lateral edges of the mandibles very long and numerous, forming well-developed ammochaetae. Hairs on the upper surface of the mandibles very short and subappressed. Clypeal border with numerous long curved hairs. Those on the dorsal surface of the head sparse and of variable length but averaging longer than those of the thorax and pedicellar nodes. Gaster with moderately numerous short hairs all of approximately the same length. Legs clothed with short whitish hairs which are more numerous on the tibiae and tarsi than on the femora. Scapes covered with exceedingly fine hairs which grade into golden pubescence on the apical funicular joints.

Color piceous brown to jet black, the mandibles, antennae, and legs somewhat lighter than the remainder of the insect.

Worker minor: Length 2.5 mm.

Differs from the major in the following characteristics: the head is slightly longer than broad, with the occipital border feebly convex in the middle. The antennal scapes in repose surpass the occipital border by an amount slightly in excess of their greatest diameter, the impression at the mesoëpinotal suture is relatively broader and shallower, the sculpture is feebler, the pilosity, especially that of the gaster, is much sparser.

Medias vary between the extremes described above, depending upon their size.

To date no description of the sexual forms of *pergandei* has appeared in myrmecological literature. The following descriptions are based upon a large series of males and females taken by the senior author in Fenner Canyon, Santa Catalina Mts., Arizona.

Female: Length 10 mm.

Head, mandibles excluded, quadrate, slightly broader than long, the straight sides slightly narrower in front of the eyes than behind them, the occipital angles very broadly rounded, the middle of the

occipital border flat. Mandibles large, their outer margin less strongly curved than in the major worker. Apex of the masticatory margin armed with two long, very stout and sharp terminal teeth, the outer tooth stouter and longer than the inner, but both far larger than the row of short, triangular teeth which arm the rest of the masticatory margin. Clypeus short, its anterior margin feebly projecting and sinuate in the middle. Median lobe with a single projecting tooth as in the major worker. Frontal carinae short and rather flat, not bounding the antennal fossae in the rear, the frontal area between them arrow-shaped, only a little depressed, and feebly shining. Antennal scapes stout, their diameter gradually increasing from base to apex, the tips only slightly turned outward. In repose the scape surpasses the occipital margin by an amount slightly in excess of its greatest diameter. All funicular joints longer than broad, their diameter gradually increasing from base to apex, the first and last joints slightly longer than the rest. Eyes large, moderately convex and reniform in outline, set somewhat behind the middle of the side of the head, with their long axes slanting forward and downward. Ocelli well-developed, the median ocellus varying considerably in size and shape throughout the type series. In some specimens it is round and no larger than the lateral ocelli, in others it is oval and notably larger.

Thorax bulky, oval when seen from above; its greatest width, which occurs behind the middle of the scutum, slightly more than half its length. Scutum large, its evenly and strongly convex anterior edge completely obscuring all but the projecting neck of the pronotum when the thorax is viewed from above. Paraptera poorly developed and apparently fused to the adjacent portions of the scutum and scutellum; the former sutures being indicated merely by impressions at either side of the paraptera. Scutellum subtrapezoidal with the angles rounded, largely concealing the metanotum when seen from above. Epinotal spines seen from above short and stout, with rather bluntly rounded tips. Seen from the side, the almost vertical anterior face of the pronotum is overhung by the bulging forward edge of the scutum. The greater part of the scutum and the scutellum together form a straight dorsum to the thorax. Mesothoracic sternite separated from the epimeron by a well-marked impression. Basal and declivous faces of the epinotum not sharply separated, together forming a single steep and slightly convex slope with the two bluntly triangular epinotal spines at the middle.

Peduncle of the petiole very thick, with a prominent antero-ventral tooth. Seen in profile, its dorsal face forms an unbroken slope with the anterior face of the node. The latter is small, triangular, and with a narrow though blunt summit. Posterior peduncle of petiole exceedingly short and thick. Postpetiole cupshaped in profile, larger than the petiole, with a very short anterior peduncle and no posterior peduncle, the entire, wide, posterior face being applied to the surface of the gaster. Seen from above, the node of the petiole is only about three-quarters as wide as the subcuneiform peduncle below it. Postpetiole subtrapezoidal, with the lateral faces slightly convex, its greatest width two-fifths again as wide as the petiole. Gaster long, suboval, with a flattened anterior border. Femora not incrassated. Wings tinged with yellow, the veins and stigma brownish yellow.

Mandibles shining, with strong, subparallel rugae. Portion of the clypeus adjacent to the median tooth with longitudinal rugae, the lateral portions finely granulose, the granulation being replaced at the extreme ends by striae which are carried backwards onto the front and curving around the lateral edges of the antennal fossae. Frontal carinae with longitudinal striae, which spread fan-wise on the vertex but do not reach the occiput. The entire head covered with small, piligerous punctures. These are most numerous on the vertex and occiput where they tend to replace the longitudinal striae which become very feeble on the posterior parts of the head. On the front the punctures are sparser and at the anterior edge of the head, where the striae are heavy, they disappear altogether. Thorax in large part smooth and more shining than the head. The scutum and scutellum with scattered punctures smaller than those on the head. Lateral portions of the pronotum, the epimeron and the upper part of the mesothoracic sternite coriaceous, with very feeble striae impressed upon the coriaceous marking so that these parts appear striate or coriaceous, depending upon the angle of illumination. Lower portion of the mesothoracic sternite and epinotum with coarse, wavy, longitudinal rugae, the interrugal spaces finely granulose and less shining than the remainder of the thorax. Petiolar nodes coriaceous, scarcely shining. Gaster strongly shining, feebly shagreened, with scattered small puncture.

Pilosity as in the major worker except for the gaster, on which the hairs are less uniform, those at the edge of each segment being longer, thicker, and more numerous than elsewhere.

Color piceous black, the mandibles, anterior border of the head, funiculi, and tarsal joints clear, reddish brown; the scapes, tibiae, femora, and abdomen piceous brown.

Male: Length 8.5 mm.

Head small, quadrate, notably wider behind the eyes than in front of them, the feebly convex occipital border passing through much-rounded occipital angles to the very short part of the sides which lies behind the eyes. Mandibles as in the female, except that they are relatively much less massive and somewhat narrower. Anterior border of clypeus feebly convex, with a broad median impression, the median lobe projecting but without the central tooth characteristic of both major worker and female. Eyes large, suboval in outline, with their anterior border carried well under the genae. The antennal scapes in repose reach the lateral ocelli. All funicular joints longer than broad, their diameter gradually increasing from base to apex of the funiculus. First funicular joint subcampanulate or trumpet-shaped, notably broader than the adjacent joint although not equaling it in length. Funicular joints 2-6 as broad basally as apically, joints 7-11 subovoidal, with the basal ends somewhat constricted, the terminal joint rather sharply pointed and as long as the two preceding joints together.

Thorax bulky. In profile the scutum shows a flat posterior half and a strongly convex anterior portion which slightly overhangs the pronotum. Scutellum in profile with its anterior edge slightly higher than the adjacent portion of the scutum from which it is separated by a broad suture. Posterior edge of the scutellum overhanging the very short, strap-like metanotum. Basal face of the epinotum longer than the declivous face, the angle between them well-marked and armed with a broad, short, somewhat rounded tooth at either side. Seen from above the thorax is suboval, the anterior border evenly convex, the declivity of the epinotum forming a flat, truncated posterior face. The greatest width of the thorax occurs at the posterior third of the scutum. Mesothoracic paraptera virtually obliterated, their place being taken by a broadly impressed suture between the scutum and the scutellum. Notauli absent.

Nodes of pedicel as in the female, except that the posterior face of the postpetiole is even more broadly applied to the anterior surface of the first abdominal segment without any constriction between the two. In profile this gives the postpetiole the appearance of being a narrowed portion of the gaster rather than a separate node.

Head and mandibles finely striate-granulose and feebly shining. Median lobe of clypeus irregularly rugose, in some specimens with a median crest extending back onto the front. Dorsum of the thorax shining, the sculpture coarser but notably sparser so that there are large glabrous areas, particularly in the middle of the scutum. Sides and lower portions of the thorax feebly shining or opaque, densely striate-granulate. Petiolar nodes finely granulose, opaque. Abdomen strongly shining, rather strongly shagreened, and with numerous small punctures.

Hairs numerous, golden, erect or suberect, curved, fairly long, and of about equal length on head, thorax and abdomen. Those on the gulae and mentum form a small but distinct psammophore. Hairs on the legs short, fine, and suberect. Those on the antennae finer and appressed.

Color piceous black, the apical third of the mandibles and all of the tarsal joints castaneous brown, the funiculi castaneous basally but becoming clear, golden yellow toward the apex. Wings as in the female.

In his original description Mayr cites California as the type locality of *pergandei*. The authors have seen material from the following localities:

California: Mojave. (J. C. Bradley and A. Wetmore.)

Apple Valley. (E. C. Jaeger.)

Santa Barbara (F. E. Clements.)

Palm Springs, Needles, Lakeside, Claremont. (W. M. Wheeler.)

Coachella Valley. (S. F. Light.)

Elsinore. (C. F. Baker.)

Otis, Perris. (J. C. Bradley.)

Victorville. (W. S. Creighton.)

Fresno. (Woodworth.)

Salton Sea, San Jacinto, Moore Canyon, Menifee, San Diego County. (No collector.)

Arizona: Nortons, Tempe, Casa Grande, Gila Bend Mts., Fenner Canyon, Santa Catalina Mts., Yucca, Yuma. (W. M. Wheeler.)

Ft. Mojada. (J. Henderson.)

Tucson. (G. von Krockow, W. M. Wheeler, E. A. Carpenter, N. C. Skinner.)

Mexico: San Julio, Lower California. (Eisen?)

Santa Borja, Lower California. (C. D. Haines.)

The examination of a large amount of material in the collection of the senior author shows that *pergandei* exhibits a certain degree of morphological instability. That slight differences in color and sculpture do occur has been noted in the foregoing descriptions. It is, moreover, also possible to select individuals in which the length of the epinotal spines is reduced. This last character is usually confined to the minor worker, a caste in which the spines are sometimes replaced by mere angles. Were any of these variable characters constant throughout a series from a single nest they might be utilized as a basis for varietal status. Actually, however, any or all of them may appear in a nest series and this, in the opinion of the authors, unfits them for use as taxonomic characters.

Of all the species in the genus *Veromessor*, *pergandei* appears to be most completely adapted to a xerophilous mode of life. This might logically be inferred from the structural characters because of the unusual development of the ammochaetae. In this species not only are the gular and mental hairs very long and numerous but, in addition, they are augmented by another row of hairs arising along the lower lateral border of each mandible. These accessory ammochaetal hairs do not occur in the other species of *Veromessor*. An examination of the locality records presented above will show that *pergandei* occurs in areas of extreme aridity and high temperature. The fact that a number of the records come from the Mojave and Imperial Deserts needs no further comment to anyone familiar with the climatic conditions in those areas.

The habits of *pergandei* have been summarized by the senior author as follows: "The nests are single or more rarely multiple craters, much flattened, with rounded slopes, 50 cm. or more in diameter, and with one to three large and very irregular central openings. Sometimes these are slit-shaped and as much as 5 or 6 cm. long. The rough galleries and granaries are excavated to a depth of at least 60 cm. in the hardest and most sunbaked portions of the desert soil. Late in the afternoon long files of workers may be seen in the full activity of harvesting. Sometimes these files may be followed for a distance of 20 or 30 meters from the nest before the ants disperse among the scant vegetation in search of seeds. They seem to have no preferences, but eagerly seize all the mature seeds they find and carry them to the nest where they carefully remove the husks and store the edible kernels in the granaries. The chaff and seed-pods are then carried out and dumped on the kitchen midden, which forms a crescentric or circular

zone at the periphery of the crater. Sound seeds are often thrown out with the chaff and eventually germinate, so that old nests are often marked by a circle of growing plants. . . ."

It may be added that *pergandei* is one of our few desert ants that does not remain in the nest during the middle of the day in the summer months. The junior author observed it foraging at noon on the Mojave Desert in August. The temperature optimum for this insect must be exceedingly high and this point offers interesting ecological possibilities for anyone who has the temerity and constitution necessary for a mid-summer study of the species.

***Veromessor relictus* (Wheeler and Mann).**

V. relictus (Wheeler and Mann), Bull. Amer. Mus. Nat. Hist. Vol. 33, p. 25, fig. 8c. (1914). ♂ ♀ ♂ (Aphaenogaster).

Worker: Length 4–5 mm. (Plate II, fig. 4.)

Head, exclusive of the mandibles, one and one-third times as long as broad, the sides slightly convex, scarcely narrowed from the eyes to the insertion of the mandibles, more strongly narrowed toward the occiput. Occipital angles very poorly marked, the occipital border narrow and somewhat convex. Mandibles of moderate size, their outer margin straight, except at the apex where it suddenly curves inward. Masticatory margin armed with two long, sharp, terminal teeth, with a smaller tooth just inside them, the remainder of the margin feebly serrate. Clypeus not strongly projecting, its anterior edge evenly convex and coarsely serrate, with a notch in the middle. Median lobe of the clypeus well developed, much longer than broad. Frontal carinae very narrow and strap-like, scarcely covering the antennal insertions, their subparallel posterior portions largely obscured by the heavy cephalic sculpture. Antennal scapes long, very little curved, evenly increasing in thickness toward the apex, with a trumpet-shaped expansion at the base. In repose the scapes surpass the occipital border by two-fifths of their length. All funicular joints longer than broad, the first only a little shorter than the two succeeding joints taken together; joints 2–10 approximately the same length but gradually increasing in thickness, the terminal joint as long as the two preceding joints taken together. Eyes of moderate size, round in outline, strongly convex, and situated just a trifle in front of the middle of the sides of the head.

Seen from above, the neck of the pronotum is rather narrow and projects strongly. Behind this the anterior edge of the pronotum is

very strongly rounded, as are the lateral portions where it passes into the mesonotum. The latter is notably constricted in front but increases in width behind. This gives the promesonotum a violin-shaped outline when seen from above. Epinotum from above subrectangular, the sides not constricted at the mesoëpinotal suture. Epinotal spines from above feebly divergent and almost straight, with their slightly thickened bases set well apart. Seen in profile, the dorsum of the promesonotum forms a single feebly convex surface. There is a wide, though shallow, impression of the dorsum at the mesoëpinotal suture. Basal face of the epinotum straight, not much lower than the promesonotum, and almost twice as long as the steeply sloping declivous face. Epinotal spines acute, sharply elevated, and slightly deflected.

Petiole, seen in profile, with a rather thick anterior peduncle which is strongly narrowed in front of the spiracular openings. Behind these its upper surface forms an unbroken concavity with the anterior face of the node. The latter has a sharp crest and a convex posterior face which slopes steeply to the short, thick posterior peduncle. Seen from above, the anterior peduncle of the petiole gradually increases in width to the base of the node, which is no wider than the peduncle itself at that point and narrower than the thick posterior peduncle. Postpetiole from above narrower in front than the adjacent portion of the petiole but rapidly expanding behind, the sides evenly convex. Postpetiole in profile with a moderately concave upper surface, its ventral surface with a pronounced, rounded, anterior fold or tooth. The greatest width of the petiole is scarcely more than one-half that of the postpetiole. Gaster oval, somewhat larger than the head. Legs long and stout.

Mandibles feebly shining and covered with longitudinal striae. Head and thorax strongly reticulate-rugose with the interrugal spaces strongly granulose. On the thorax this sculpture obscures the sutures to such an extent that it is difficult to see them unless the insect is held in such a position that the suture is revealed by the impression adjacent to it. Dorsal and ventral surfaces of the anterior peduncle smooth and shining. The remainder of the petiole, the entire postpetiole, the greater part of the dorsum of the first gastric segment, the antennal scapes, the neck of the pronotum, the fore coxae, and the fore and middle femora densely granulose and opaque. Hind femora, tibiae, and the dorsal edges of the abdominal segments more feebly granulose and somewhat shining. Epinotal spines smooth

apically but feebly striate or granulose at the base. Ventral surface of the abdomen smooth and shining.

Hairs moderately long, in color whitish tinged with brown, rather numerous on the head, promesonotum, and fore femora; sparser on the middle and hind femora, the epinotum, and petiolar nodes; abundant on the abdomen. Scapes and tarsi with numerous fine, short, suberect hairs. Funiculi with similar hairs which grade into pubescence toward the tips.

Color jet black, the mandibles rich, reddish brown, the tarsi and funiculi a somewhat duller brown. In some specimens the postpetiole and a large part of the first gastric segment adjacent to the postpetiole may be orange yellow. In other specimens these areas are black.

Redescribed from type material in the collection of the senior author.

For the characteristics of the sexual forms the reader is referred to the original description of this species.

Relictus is known only from the material taken by Dr. W. M. Mann at Diquini, Petionville, Port au Prince, and Jacmel in Haiti. The exact status of this curious insect is difficult to determine. The length of the head and the antennal scapes certainly suggest a relationship to *Aphaenogaster* rather than to *Veromessor*, since in the latter group the head is usually quadrate, with scapes which do not greatly surpass the occipital margin. On the other hand, the structure of the thorax and petiolar nodes relates *relictus* to *Veromessor* rather than to *Aphaenogaster*. It may subsequently be necessary when *relictus* is better known to set up a separate genus to receive it. It is not likely to be confused with any other species of *Veromessor*. Its exceedingly coarse, reticulate sculpture and the granulose dorsum of the first gastric segment separate it from any of the others in the genus. Our only observation on the habits of this ant is that of Dr. Mann, who states that: "it nests in holes beneath stones in moist localities, usually on hillsides. The workers are timid and very rapid in their movements."

***Veromessor relictus* subsp. *epinotalis* (Wheeler and Mann).**

V. relictus subsp. *epinotalis* (Wheeler and Mann), Bull. Amer. Mus. Nat. Hist. Vol. 33, p. 27, fig. 8a. (1914). ♂ (*Aphaenogaster*).

Only the worker of this form is known. It differs from the typical *relictus* in having shorter and straighter epinotal spines and a pronounced impression on the dorsum of the epinotum. Type locality: Manneville, Haiti (W. M. Mann).

Veromessor stoddardi (Emery).

V. stoddardi (Emery), Zool. Jahr. Syst. Vol. 8, p. 307, (1895). (*Stenamma* (Messor)).

Worker: Length 4–6 mm. (Plate II, fig. 1.)

Head exclusive of the mandibles as broad as long, with approximately straight sides, which are slightly narrowed in front of the eyes. Occipital angles only slightly rounded, the flattened portion of the occipital border, which extends almost the full width of the head, with a broad and very feeble median excavation. Clypeus feebly projecting, its anterior edge with a broad, rounded, and rather shallow median impression. Median lobe of the clypeus without carinae but with prominent longitudinal rugae at either side, approximately rectangular in outline and extending well back between the rather short frontal carinae. Frontal area triangular, slightly depressed, opaque. Mandibles large and triangular, the outer margin moderately and evenly curved, the junction between the outer and masticatory margins armed with two large blunt teeth which are set close together and form a small terminal lobe to the mandible, the remainder of the masticatory margin feebly and irregularly serrate. Eyes of moderate size with 16–18 facets in their greatest diameter, feebly convex and circular in outline, except for a small straight ventral portion. The posterior margin of the eye lies at the middle of the side of the head. The antennal scapes in repose fail to reach the occipital margin by a distance twice as great as their maximum diameter. Basal two-thirds of the scape viewed from front straight and thin, the apical third strongly swollen, with the tips turned slightly outwards. Funicular joints gradually increasing in thickness apically, all of about the same length except the basal and terminal joints, which are slightly longer than the rest.

Promesonotum, seen from above, with an evenly rounded anterior border which passes without distinct humeral angles into the straight sides, the latter converging strongly toward the mesoëpinal suture where they meet the short, transverse posterior border in a rather sharp angle. Sides of the thorax not constricted at the mesoëpinal suture, the epinotum subrectangular in outline, slightly narrower behind than in front and with the sides strongly sloping inward to the dorsum. Epinotal spines slender, feebly divergent, and shorter than the distance between their bases. Seen in profile, the promesonotum is evenly though feebly convex and notably higher than the epinotum to which it abruptly descends by means of a short, almost perpen-

dicular posterior face. Mesoepinotal suture broad and prominent though not deeply impressed. Basal face of the epinotum with a short, straight anterior portion which forms a distinct angle with the longer, strongly slanting posterior portion. Declivous face of the epinotum short, only slightly more sloping than the posterior half of the basal face, the very wide angle between the two faces armed with short, straight, acute spines.

Petiole, in profile, with the thick anterior peduncle increasing in diameter toward the base of the node and bearing a prominent ventral lamella. Node small, somewhat inclined backwards, the summit blunt and rounded, the anterior face forming a very wide angle with the dorsum of the peduncle, the posterior face meeting the short, thick posterior peduncle at a sharper angle. Postpetiole in profile notably larger than the node of the petiole, its dorsum strongly gibbous and passing posteriorly to a very thick posterior peduncle; ventral face notably concave, with a marked, angular, ventral projection at its anterior border. Seen from above, the anterior portion of the peduncle of the petiole is notched at either side by an angular constriction. Posterior to these notches the petiole is bluntly cuneiform, widest behind the node, and one-half as wide as the suboval postpetiole. Gaster oval, its anterior border not flattened at the insertion of the postpetiole but with the portions immediately adjacent to the postpetiole bearing very short, even, parallel striae which give it the appearance of the milled edge of a coin. Femora rather strongly incrassated.

Head feebly shining, its anterior half covered with fine, subparallel rugae which are interrupted by numerous, coarse, punctures. On the posterior half of the head they are less prominent and more irregular, degenerating into wavy areas separating the numerous large, elongate punctures. Mandibles moderately shining, with somewhat coarser rugae than the head. Lateral portions of the clypeus finely punctate, the median lobe with a few longitudinal rugae at either side. Antennal scapes shagreened. Promesonotum less shining than the head, the dorsum with fine parallel striae, the sides dull and striate-granulose. On the epinotum the granulation almost completely replaces the striation except for certain portions of the pleura. Petiole and postpetiole densely granulose. Gaster shining, feebly shagreened, with numerous very small piligerous punctures.

Hairs on the body short, numerous, erect and golden. Their length is fairly uniform, except for a few somewhat longer ones on the petiolar

nodes, promesonotum, and front of the head. The hairs on the genae, gula, and mentum are short and do not form ammochaetae. Hairs on the legs abundant, short, and erect. Antennal scapes with numerous fine short erect hairs. Funiculi with very fine hairs which are replaced by pubescence on the apical joints.

Color rich reddish or yellowish brown, the borders of the mandibles and the abdomen piceous brown.

It may be noted here that in the smaller workers the head is slightly longer than broad and the antennal scapes extend almost to the occipital border. In other respects they conform to the above description.

Sexual forms unknown.

Redescribed from type material in the collection of the U. S. National Museum. The type series comes from several localities all in San Diego County, California. It seems preferable, for this reason to regard San Diego County as the type locality. *Stoddardi* would seem to be rare or very local in its distribution. The senior author has taken one worker at Jacumba, California, on the border of Mexico, but with the exception of this specimen the species appears to be known only from type material.

Because of its unusually short epinotal spines, *stoddardi* is not likely to be confused with any of the other species in the genus, with the possible exception of *pergandei*. In the case of the latter species, however, there are so many other differences that confusion is extremely unlikely. The dark color, elongate eyes, well-developed ammochaetae, and smooth integument of *pergandei* all serve to distinguish it from *stoddardi*.

Nothing is known of the habits of *stoddardi*. Mention has already been made of the lack of ammochaetae in this species, and their absence might be taken to indicate incomplete xerophilous adaptation. It is to be hoped that subsequent field observations will round out our knowledge of this species.

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EXPLANATION OF THE PLATES.

PLATE I.

- FIGURE 1. Head of *N. cockerelli* E. André. ♂.
FIGURE 2. Head of *N. manni* sp. nov. ♂.
FIGURE 3. Head of *N. albisetosus* Mayr. ♂.
FIGURE 4. Thorax of *N. cockerelli* E. André. ♂.

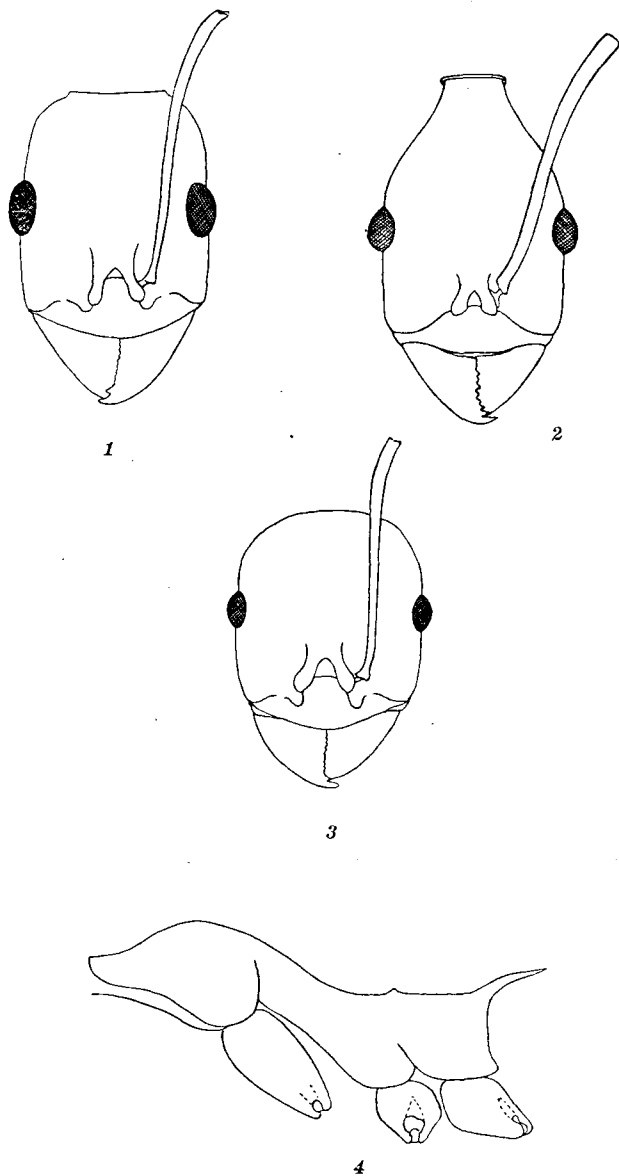
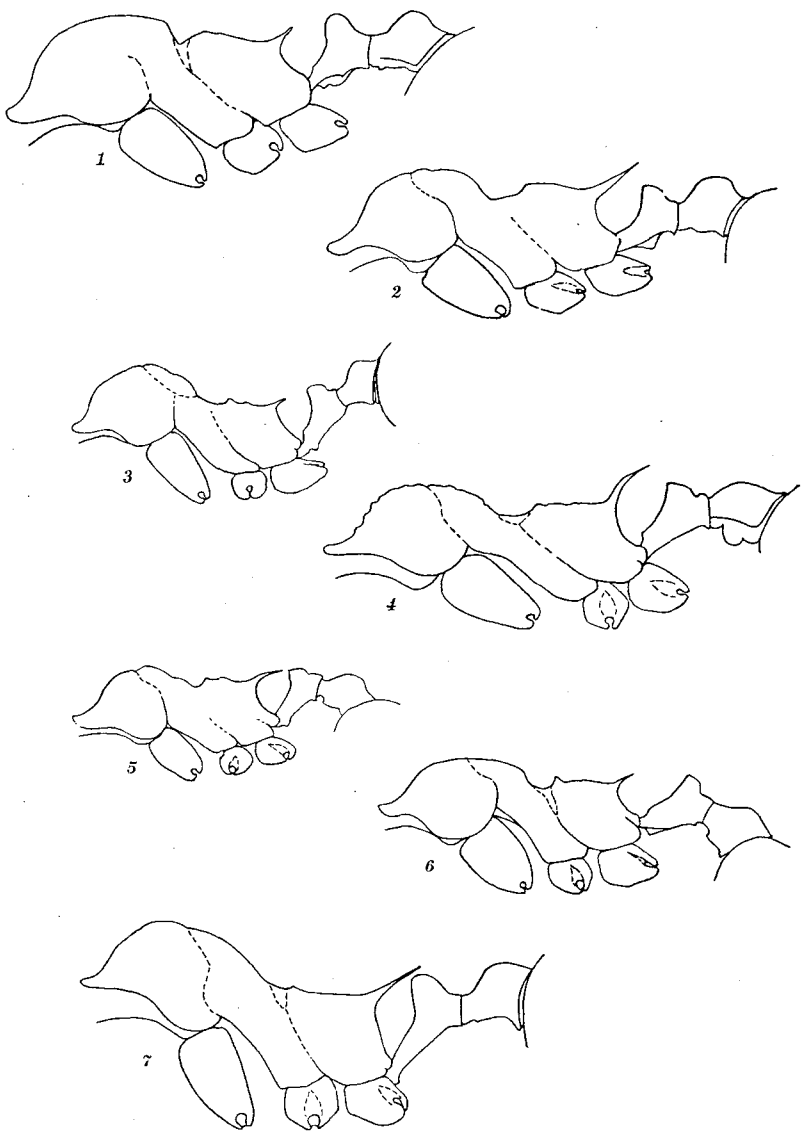


PLATE II.

Thorax and pedicel of various species of Veromessor.

- FIGURE 1. *V. stoddardi* Emery. ♂.
- FIGURE 2. *V. andrei* Mayr. ♂.
- FIGURE 3. *V. pergandei* Mayr. ♂.
- FIGURE 4. *V. relictus* Wheeler and Mann. ♂.
- FIGURE 5. *V. chamberlini* Wheeler. ♂.
- FIGURE 6. *V. lobognathus* Andrews. ♂.
- FIGURE 7. *V. julianus* Pergande. ♂.



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THE APPARATUS AND METHOD USED FOR THE
MEASUREMENT OF THE COMPRESSIBILITY OF
SEVERAL GASES IN THE RANGE 0° TO 325° C.

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1. INTRODUCTION.

THE experimental investigation of the compressibility of a pure fluid requires the measurement of four quantities—mass, pressure, volume, temperature—and the accurate control of two of these quantities, usually volume and temperature. Keyes¹ has described the apparatus used in the investigation of the compressibility of water; in the present paper are described the disposition of apparatus (many of the individual parts of which are similar to or identical with those of Keyes) and the procedure used in the investigation of the compressibility of the gas phase of several substances.

The temperature range that can be covered is limited at the lower end by the freezing point of mercury under pressure and at the upper end (325° C) by the uncertainties introduced by the presence of appreciable amounts of mercury vapor. The pressure range covered is from 10 to 500 atmospheres. Above 500 atmospheres hysteresis in the dilation of the apparatus begins to appear and affects the accuracy of the volume measurements. An advantage of the method is that the effect of temperature and pressure on the volume measuring system is experimentally determined.

The individual units for the determination of mass, pressure, volume, and temperature have been carefully checked over a period of years. Pressures are expressed in terms of the vapor pressure of carbon dioxide at 0° C (34.401 normal atmospheres), the volumes of the gas at any temperature are expressed in terms of the specific volume of liquid mercury at that temperature and one atmosphere, temperatures are expressed on the international platinum resistance thermometer scale.

2. THE APPARATUS.

The general disposition of the apparatus is shown in Fig. 1. A weighed portion of the gas is contained in the bomb *F* of about 200 cc.

¹ F. G. Keyes, Proc. Am. Acad. Arts and Sci., **68**, 505 (1933).

capacity. The volume of the gas space is controlled and measured by the introduction or removal of known volumes of mercury by means of the mercury compressor *C* of about 210 cc. displacement, which is connected to the bomb by steel capillaries. The temperature of the gas is controlled by the thermostat *G* and the control platinum resistance thermometer *T'*, and measured on the platinum resistance thermometer *T*. The pressure is measured on the gauge *B*, being transmitted by oil from the tip of the insulated needle in the riser-block *D* to the gauge.

Measurement of Pressure. The pressure gauge, Fig. 2², is of the Amagat dead-weight type, and is a development from an earlier design of Keyes.³ The cylinder *F* carrying the piston *C* is held in the

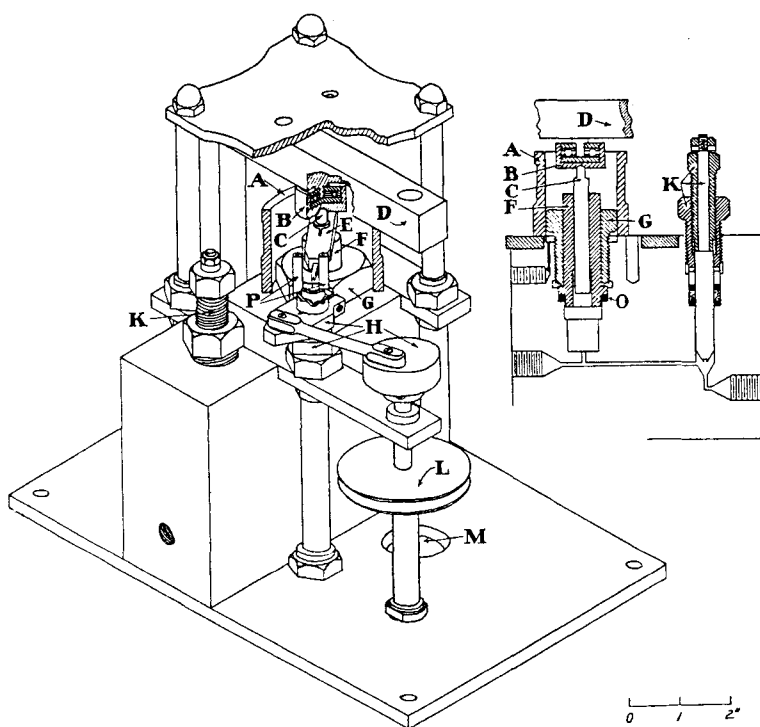


FIGURE 2. The Pressure Gauge

² This is a reproduction of Fig. 4 of Keyes, reference 1.

³ F. G. Keyes and R. B. Brownlee, "The Thermodynamic Properties of Ammonia." New York: John Wiley and Sons, 1916.

block by a nut G that presses the bottom of a flange on the cylinder against an aluminum gasket O . Several piston and cylinder combinations of different effective areas may be used interchangeably in the same block, since the cylinders all have the same external dimensions. The weights used to balance the thrust due to the pressure are placed on a scale pan (see Fig. 1) suspended from the cross-arm D that rests on a ball-bearing B at the top of the piston. The piston is rotated backwards and forwards 30 times a minute through an angle of 60° by means of two rollers P that alternately engage the clip E fastened to the piston. At the end of each stroke there is a short time during which the clip E is not in contact with either of the rollers P ; and it has been found that in this interval the piston is not in electrical contact with the cylinder and hence is floating freely in oil. The free vertical travel of the piston is about 1 cm. The oil that leaks out around the piston is replaced from an oil injector A , Fig. 1.

The pistons and cylinders are hardened, ground, and lapped, and are manufactured by Pratt and Whitney Company. The requirements⁴ of a proper piston and cylinder combination are: (1) the maximum variation in diameter of the piston throughout its entire length should be 0.0001 cm. or less; (2) when lubricated with oil and pushed back and forth through the cylinder several times, the piston should slide through the cylinder under a force of 100 grams with a velocity of about 1 cm. per second without sticking in any position; and (3) under a load of 250 kilograms (the maximum used) the piston should sink, due to oil leakage between piston and cylinder, not faster than 1 cm. in 20 minutes. The oil used for the last two tests should have a viscosity of about 50 centipoise at 38°C .

The relation between the constant C' of a piston-cylinder combination in normal mm. of mercury (1 mm. = 1/760 normal atmospheres) per gram-weight (1 gram-weight = g dynes) and the effective diameter d_e in centimeters is

$$C'd_e^2 = \frac{40g}{\pi\rho g_s} = 0.000955008g, \quad (1)$$

where ρ is the standard density of mercury (13.5951 gm. per cm.³), g the value of gravity at the place where the gauge is used, and g_s standard gravity (980.665 dynes per gram).

The effective diameter of a proper piston-cylinder combination calculated from the formula

$$Cd_e^2 = 0.000955008g, \quad (2)$$

⁴ J. A. Beattie and O. C. Bridgeman, *Ann. der Physik*, [5] **12**, 827 (1932).

where C is the gauge constant in normal mm. of mercury per gram of brass-in-air (1 gram of brass-in-air = $(1 - 0.0012/8.4)$ g dynes = 0.99986 g dynes), is very closely 0.00025 cm. greater than the actual diameter d of the piston. The constant C computed from the relation

$$C = \frac{0.000955008 \text{ g}}{(d + 0.00025)^2} \quad (3)$$

is usually within $\pm 0.03\%$ of the actual constant.

The following considerations should be mentioned:

1. The gauge constant C is determined by calibration against the vapor pressure of carbon dioxide at 0° C. as described by Bridgeman.⁵ His value of this vapor pressure—26144.7 normal millimeters or 34.401 normal atmospheres—is used. The calibration can be made with a precision of 0.004%.

2. For both the calibration and the subsequent use of the gauge, the weight of the scale pan, cross-arm, ball-bearing, piston, clip, and the "weights" are determined by weighings in air against brass standards and are not corrected for air buoyancy. This correction is unnecessary since the maximum effect of variations in air buoyancy is less than one part in 100,000.

3. It has been found⁶ that the variation of the gauge constant with pressure does not exceed 0.02% in the range from 10 to 500 atmospheres.

4. The variation of the gauge constant with temperature due to thermal expansion of the steel is given by the relation

$$C_{t_2} = C_{t_1} [1 + 2.2 \times 10^{-5}(t_2 - t_1)], \quad (4)$$

where $t_2 - t_1$ is expressed in Centigrade degrees.

5. The gauge constant increases (*i. e.* the effective area decreases) with time,⁴ this increase being approximately 0.01% per year for a new piston-cylinder combination.

6. In the correction for oil-level difference, the level in the gauge is taken at the bottom of the piston. If the level were taken at any other place on the piston a correction for the buoyant effect of the oil must be applied which exactly compensates for this difference.

The riser-block D , Fig. 1, for the detection of pressure equilibrium³ consists essentially of a steel tube of 3/16 inch bore into the top of which projects an electrically insulated steel needle.¹ Above the tip

⁵ O. C. Bridgeman, J. Am. Chem. Soc., **49**, 1174 (1927).

⁶ F. G. Keyes and J. Dewey, J. Opt. Soc. Am., **14**, 491 (1927); J. A. Beattie and W. L. Edel, Ann. der Physik, [5] **11**, 633 (1931).

of the needle is the oil which transmits the pressure to the gauge and below is the mercury of the volume control system. When there is too little weight on the scale pan the mercury surface rises and makes electrical contact in the grid circuit of a thyatron, when there is too much weight the mercury surface falls and electrical contact is broken (see Fig. 1). A pilot light in the anode circuit of the thyatron indicates when contact is made or broken. Thus the leakage of oil around the piston of the pressure gauge, if not too great, has no effect on the detection of pressure equilibrium. When other things are constant, a change in weight of 0.001% to 0.002% on the scale pan produces a positive effect within 1 to 2 minutes.

Control and Measurement of Temperature. The thermostat *G*, Fig. 1, has been described in detail elsewhere.⁷ The outer can is of galvanized iron and is 39 inches deep by 29 inches in diameter. The inner vessel is made by welding a bottom into a 28 inch length of wrought iron pipe 14 inches in diameter and 5/16 inch wall thickness. It rests on fire brick and is surrounded by 85% magnesia. It is wound with three 50-foot 20-ohm heaters through which sufficient current is passed to keep the temperature 2° to 3° below the desired operating value.

The stirrers are suspended between two plates one of which rests on the bottom of the inner vessel and the other turned to a tight fit to the top of the inner vessel. Three shafts each carrying three propeller-type stirrers and each enclosed in a steel tube 2-3/4 inches in diameter are spaced 120° apart and run in bearings at the top and bottom. The shafts are geared together and rotated at about 1700 revolutions per minute. The bomb and platinum resistance thermometers are introduced through tight-fitting split heads. For temperatures to 125° C, Socony Mineral Seal oil (a high grade kerosene) is used as the bath fluid; for temperatures above 125° C, Socony Vacuum S/V Valrex oil A. mineral (a heavy cylinder lubricating mineral oil) is used. At 325° C. this oil decomposes, but not rapidly enough to cause trouble.

In the top of each stirrer tube is inserted a flat-type heater of about 30 ohms resistance. The three heaters are connected in series and are used for the final adjustment and the regulation of temperature.

The method of regulation is a development of methods previously used.⁸ A flat-type platinum resistance thermometer is placed in the

⁷ J. A. Beattie, *Rev. Sci. Instr.*, **2**, 458 (1931).

⁸ J. R. Roebuck, *Proc. Am. Acad. Arts and Sci.*, **60**, 537 (1925); L. B. Smith, *Mech. Eng.*, **48**, 153 (1926); J. A. Beattie and D. D. Jacobus, *J. Phys. Chem.*, **34**, 1254 (1930); F. G. Keyes, *Proc. Am. Acad. Arts and Sci.*, **68**, 505 (1933).

bath and its resistance balanced on a Wheatstone bridge which is connected to a galvanometer in the usual manner. A beam of light is reflected from the galvanometer mirror to a selenium cell contained in a dark box about 20 feet away. The variation in resistance of the selenium cell is used to control the current input to the internal heaters by means of the phase-shifting thyatron circuit, Fig. 3, proposed by Hull.⁹ As the temperature of the thermostat drops the spot of light from the galvanometer moves so as to illuminate a larger area of the selenium cell, thus decreasing its resistance, whereby the current in the anode circuit (which contains the internal heaters) increases; as the temperature of the thermostat rises the spot of light moves so as to illuminate a smaller area of the selenium cell and the heating current decreases. At about 0.5 amperes regulating

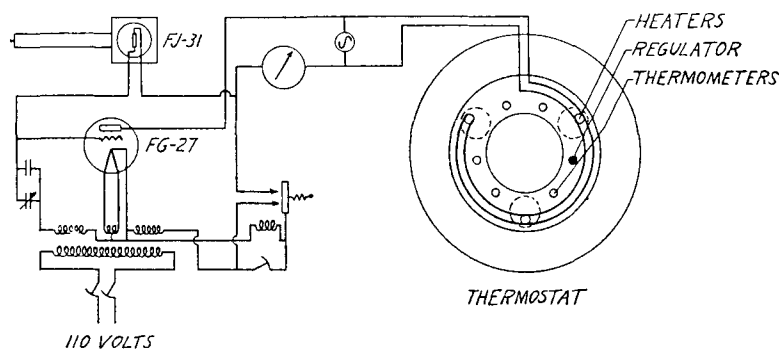


FIGURE 3. The Temperature Regulating Circuit.

current the variation due to the operation of the circuit is about ± 0.05 amperes. For best results the spot of light should not be a sharp image of the lamp filament, but rather broad. The sensitivity of the regulation depends on the correct capacity balance, which must be determined for each installation. A fixed condenser is used for the greater part of the capacity and a 0.00035 mf. variable radio condenser for the fine adjustment. In this manner thermostats have been regulated at temperatures from 25° to 325° C. to $\pm 0.0005^{\circ}$ C. for several hours, and regulation to $\pm 0.001^{\circ}$ C. can be obtained for longer periods without difficulty.

Temperatures are measured by means of strain-free platinum

⁹ A. W. Hull, Gen. Elec. Review, **32**, 390 (1929).

resistance thermometers of the mica-cross type.¹⁰ The thermometers are calibrated at the ice point (0° C), steam point (100° C), and sulfur boiling point (444.6° C). The hypsometers, which will be described in a later paper, are so arranged that the pressure at which boiling occurs can be held constant to ± 0.01 mm. and at one normal atmosphere. Interpolation is made by use of the Callendar formula:

$$t = \frac{R_t - R_o}{\alpha R_o} + \delta \frac{t}{100} \left(\frac{t}{100} - 1 \right), \quad (5)$$

where t is Centigrade temperature on the international platinum resistance thermometer scale; R_t and R_o are the electrical resistances of the given thermometer at t° and 0° C, respectively; and α and δ are two constants determined by the calibration at the steam and sulfur boiling points, respectively. For the calculation of the resistance R_t corresponding to a desired temperature t° C, the equation is written:

$$R_t = R_o \left\{ 1 + \alpha \left[t - \delta \frac{t}{100} \left(\frac{t}{100} - 1 \right) \right] \right\}. \quad (6)$$

Control and Measurement of Volume. The volume of the gas in the bomb is controlled and measured by the addition or removal of mercury by means of the mercury compressor C , Fig. 1. It consists of a cold rolled steel cylinder 1 1/16 inch inside diameter into which fits a piston of 1 inch drill rod, the packing gland at the top being made tight by cloth dipped in ceresine wax which is confined between hard rubber rings and compressed between hardened steel rings by a cap nut. The bottom of the cylinder is securely anchored to the bottom of the heavy yoke that supports and aligns the piston and cylinder. The piston is pinned to a 1 1/2 inch rod threaded with an 18 pitch buttress thread, which passes through a Tobin bronze nut. This nut passes through the top member of the yoke and has roller bearings on its upper and lower bearing surface. Full turns of the nut are registered on a revolution counter and thousandths of turns can be estimated from a calibrated dial on the nut. The compressor is thermostated at $30^\circ \text{C} \pm 0.002^\circ$. A steel capillary (1/8 inch outside diameter, 1/32 inch bore) runs from the bottom of the cylinder to the riser block and thence to the bomb containing the gas under investigation.

The piston is 1 inch in diameter and has a travel of 16 3/8 inches corresponding to 294 turns of the nut and to about 210 cc. of mercury.

¹⁰ J. A. Beattie, D. D. Jacobus, and J. M. Gaines, Jr., *Proc. Am. Acad. Arts and Sci.*, **66**, 167 (1930).

For the calibration of the compressor a very fine glass capillary is cemented to the upper end of the steel capillary and the mercury forced out by each ten turns of the nut collected in weighing bottles. The nut is first turned back to -1 turns then rotated forward to 0 turns; after a wait of ten minutes the first weighing bottle is put under the tip and the nut rotated forward to 10 turns; after a wait of ten minutes the second weighing bottle is put under the tip and the nut turned to 20 turns, etc. The cumulative volume of mercury V forced out at 30° and 1 atmosphere is expressed by the equation:

$$V = aC + \delta C, \quad (7)$$

where a is a constant and C the reading of the compressor in turns and fractions of a turn. The deviation δC from linearity is plotted against the volume V , the greatest deviation being 0.011 turns (0.008 cc). Several calibrations of the compressor and the subsequent use of it indicate that the readings are significant to 0.005 turns, or 0.004 cubic centimeters.

It will be noticed that there are two stopcocks in the mercury line, one in the riser block and one between the riser block and the bomb. They are of the type described by Keyes,¹ except that the stem is $\frac{1}{4}$ inches in diameter and the handle is fitted with a calibrated dial. The stopcocks are opened exactly the same amount each time so that no volume errors are introduced.

The Bombs. The all-steel bomb, *A*, Fig. 4, used for substances whose vapor pressure is above 15 atmospheres at 30° C, is made of chrome-vanadium steel and has a volume of about 200 cc. The closure is made on a soft steel gasket ($\frac{1}{8}$ inch wide and $\frac{1}{16}$ inch thick) made from a piece of cold rolled steel in which the carbon has been precipitated by heat treatment. The gasket is confined in a ring-shaped depression in the bottom of the bomb by a ridge on the cover, the bottom of the depression and the top of the ridge containing two slight grooves to hinder flowing of the gasket. The cap nut is tightened with an eight-foot wrench. From the bottom of the bomb a capillary leads to a cone connection *bc*, similar to that described by Keyes,¹ and thence to the riser-block. For the evacuation or filling of the bomb a gold washer 0.01 inches thick is bent up slightly in the middle, placed in the recess in the cone *c*, the drilled screw inserted, and *c* joined to the connection *a*. After the evacuation or filling is completed the drilled screw is tightened on the gold washer by means of a screw-driver that passes through a packed gland in the top of *a*. The connection *a* is then replaced by *b* and the gold washer subsequently

punctured by the application of several hundred atmospheres pressure of mercury.

The glass-lined bomb *B*, Fig. 4, is used for substances whose vapor pressure is less than 15 atmospheres at 30° C. The glass liner is evacuated or filled through a very fine capillary, the substance frozen in the bottom by immersion in liquid air, and the capillary sealed off, bent, and scratched with a file very close to the end of the bore. The liner is then placed in the chrome-vanadium steel case, the latter closed in the usual manner, and connected to the riser-block. The

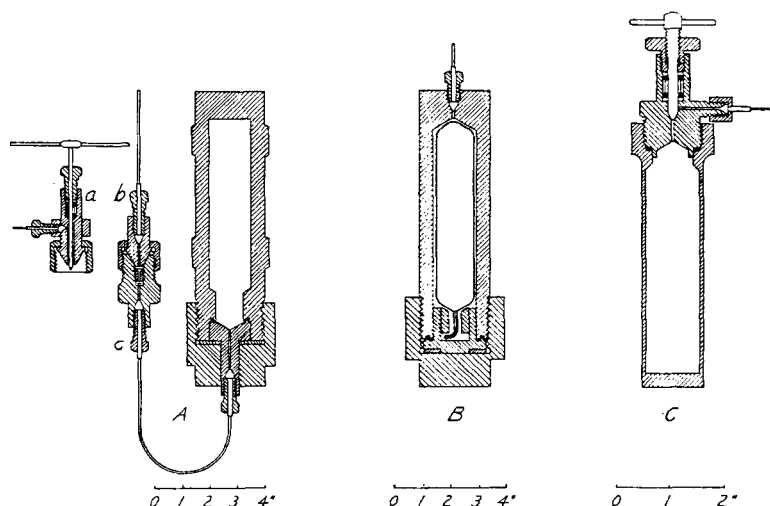


FIGURE 4. A, the All-Steel Bomb; B, the Glass-Lined Bomb; C, the Weighing Bomb.

bomb is placed on its side in the thermostat at 30° C, evacuated, mercury run in, and the bomb then turned upright. The liner floats up and the tip breaks at the file mark.

Weighing Bombs. The substance to be investigated is weighed in the stainless steel bomb *C*, Fig. 4. A second of almost identical outside dimensions is used as a tare to reduce air-buoyancy corrections to a minimum. The bomb is evacuated, rinsed out with the substance several times, approximately the desired mass of the substance introduced, and weighed against the tare. The substance is then transferred to the compressibility bomb (the latter being cooled in liquid

air), the gold washer tightened or the glass liner sealed off, as the case may be, the residual pressure read on a McLeod gauge, and the weighing bomb closed and weighed. For all weighing both bombs are closed, vacuum corrections being applied for the difference in external volume and for the weights.

In some cases the substance to be investigated has been weighed directly in the glass liner against a tare of as nearly as possible the same weight and outside dimension. Both the liner and the tare were cemented to a vacuum line, evacuated, filled with laboratory air, and the relative weight determined. The substance was then introduced into the liner, frozen in the bottom, and the liner sealed off; the tare was evacuated and sealed off; and the relative weight determined. Proper vacuum corrections were applied in both weighings. This method has not been used since the construction of the steel weighing-bombs.

3. THE BLANK RUN.

A "blank run" is first made to determine for a series of pressures at each bomb temperature the effect of pressure and temperature on the apparent volume of the apparatus, including the mercury. The riser-block is thoroughly cleaned and mercury is introduced into the mercury compressor until the end of the capillary leading from the compressor to the riser-block is just filled when the compressor reading is zero. The compressor is then turned back one turn (reading -1) and the capillary connected to the riser-block. A vacuum line is attached to the oil connection of the riser-block.

When the all-steel bomb is used it is evacuated at 400°C , the gold washer closed, the bomb placed in a thermostat at 30°C , and the bomb capillary attached to the riser-block. The bomb capillary, compressor capillary and riser-block are evacuated and mercury run out of the compressor until it fills the apparatus up to the gold washer and makes contact with the tip of the insulated needle in the riser-block. The vacuum line is disconnected, oil put into the top of the riser-block, and the pressure gauge connected. A series of settings of the compressor for pressures from 5 to 20 atmospheres is made; the gold washer broken by the application of several hundred atmospheres pressure, the bomb filled with mercury, and another series made of settings of the compressor for pressures from 5 to 20 atmospheres. The compressor reading for 30°C and 1 atmosphere (obtained by extrapolation from 5 to 1 atmospheres), corresponding to the volume up to the gold washer, is called the "zero-set"; and the reading for 30°C and 1 atmosphere, corresponding to the volume including that

of the bomb, is called the "bench volume." The difference is the volume of the bomb at 30° C and 1 atmosphere. In some of the measurements the zero-set and bench volume were made at 5 atmospheres instead of being extrapolated to 1 atmosphere; the difference is the volume of the bomb at 30° C and 5 atmospheres, which is below any pressure used in the subsequent compressibility runs.

At each temperature at which gas compressibility data are subsequently to be taken, the compressor readings corresponding to equilibrium are determined for the series of pressures 7, 13, 19, 37, 50, 170, 290, 410, 530, 410, 290, . . . 7 atmospheres. At each pressure one hour is allowed for equilibrium although in general no change is noted after one-half hour. The compressor readings in the increasing pressure series are usually less than those in the decreasing series, the greatest difference being 0.01 turn, or 0.007 cc. The average of the two values is used in the subsequent work, the compressor reading being converted to cubic centimeters of mercury by means of Eq. (7). The result is the apparent volume of the entire system at the given temperature and pressure.

The difference ΔV between the bench volume V_{bench} and the apparent volume $V_{p,t}$ of the entire system when the bomb is at t° C and p atmosphere is expressed by the relation:

$$\Delta V = V_{bench} - V_{p,t} = -(a + bt)p + (ct - a) + \Delta_t + \Delta_p, \quad (8)$$

where a , b , c , and d are positive constants, Δ_t a deviation which depends only on temperature, and Δ_p the deviation of the observed ΔV from that calculated by the first three terms of the equation. It was found that the plots of Δ_p against pressure were identical within the experimental error (0.007 cc.) at all temperatures, dropping from + 0.008 cc. at 10 atmospheres to zero at and above 50 atmospheres. Thus the reading of the mercury compressor when the bomb completely filled with mercury is at t° C and p atmospheres is given by the relation:

$$V_{p,t} = V_{bench} - \Delta V. \quad (9)$$

The difference between the bench volume and the zero-set is checked by weighing the amount of mercury in the bomb and capillary up to the gold washer. After the removal of the mercury the bomb is ready for loading with the substance whose compressibility is to be studied. If for any reason the bomb is opened, a new zero-set and bench volume must be determined, since the volume may be changed, but this slight change in volume is not great enough to effect the blank compressibility run.

When the glass-lined bomb is used, the method of procedure is similar. The steel case and the liner are each evacuated at 400°C , the liner sealed off, and enclosed in the case. The zero-set is made with the bomb on its side, the mercury filling the case around the liner. The bomb is set upright whereby the glass tip of the liner is broken and the bench volume is determined. Both the zero-set and the bench volume are extrapolated to zero pressure, the difference being the inside volume of the glass liner at 30°C and zero pressure. This volume is checked by weighing the mercury in the liner, correction being applied for the stretch due to the head of mercury.

4. THE COMPRESSIBILITY MEASUREMENTS.

It is desired to measure the compressibility of a substance along isometrics as well as isotherms. This requires setting the mercury compressor at the correct reading to give the same set of gas densities in the bomb at each temperature.

After the bomb has been evacuated at 400°C and loaded with the substance under investigation, it is connected to the riser-block, the leads evacuated, and a zero-set made. This zero-set will not coincide exactly with that previously measured, due to the difficulty of loading exactly the same amount of mercury into the compressor as in the blank run. The zero-set plus the volume of the bomb gives the new bench volume, V_{bench} .

When the glass-lined bomb is used the zero-set is extrapolated or interpolated to the vapor pressure of the substance at 30°C . A slight correction, determined from the blank run at 30° , is applied for the compressibility of the apparatus between 0 atmospheres and the vapor pressure. The new bench volume is then the new zero-set plus the inside volume of the glass liner.

The only difference between the blank run and the compressibility run is that a certain volume of mercury has been removed from the bomb at t° and introduced into the mercury compressor at 30° . The calculations require a knowledge of the thermal expansion of mercury, and gas volumes at a given temperature are expressed in terms of the volume of mercury at 1 atmosphere and the temperature in question. The density of mercury at 0°C is taken to be 13.5955 grams per milliliter and the variation of volume with temperature at 1 atmosphere pressure is given by Eq. (11), below.

Let m be the number of grams (moles) of substance in the bomb, and let v be the desired specific (molal) volume at $t^{\circ}\text{C}$ and p atmospheres. Then the correct setting C of the mercury compressor is

$$V_{p,t} = aC + \delta C = V_{bench} - mv \frac{d_t}{d_{30}} - \Delta V - D_1 + D_2 + D_3, \quad (10)$$

where:

1. V_{bench} is the bench volume for the compressibility run obtained by adding the volume of the bomb previously determined in the blank run to the zero-set for the compressibility run.

2. mv is the total gas volume, *i. e.* the volume of mercury at t° C which must be withdrawn from the bomb, and d_t and d_{30} are, respectively, the densities of mercury at t° and 30° C and one atmosphere. Since all mercury withdrawn from the bomb is measured at 30° C, the volume of mercury which must be withdrawn into the mercury compressor is $mv d_t / d_{30}$ (subject to the corrections given below).

The density d_t of mercury at one atmosphere is obtained from the formula:¹¹

$$V_t = V_o \{ 1 + 10^{-6} (181.456 t + 0.009205 t^2 + 0.000006608 t^3 + 0.000000067320 t^4) \}, \quad (11)$$

where V_t is the specific volume at t° C and V_o that at 0° C.

3. ΔV is the correction determined in the blank run for the effect of the bomb temperature t and the pressure p on the setting of the mercury compressor. It is read from plots or given by Eq. (8).

4. D_1 is the correction for the change of the compressibility of mercury with temperature and for the compressibility of the steel piston withdrawn. During the compressibility run a certain volume of mercury (approximately mv), which was at t° in the blank run, has been withdrawn into the mercury compressor at 30° , also the same volume of steel piston has been withdrawn from the compressor. The temperature coefficient of the compressibility of mercury¹² $\left(\frac{1}{V} \frac{\partial}{\partial T} \frac{\partial V}{\partial p} \right)$ is 5.5×10^{-9} per atmosphere-degree C and the coefficient of compressibility of steel $\left(\frac{1}{V} \frac{\partial V}{\partial p} \right)$ is 5.8×10^{-7} per atmosphere. Hence

$$D_1 = \{ 5.8 \times 10^{-7} + 5.5 \times 10^{-9} (t - 30) \} (p - 1) mv. \quad (12)$$

It will be noticed that at constant temperature D_1 does not vary greatly with pressure, since the pressure-volume product for a given mass of gas does not change greatly.

¹¹ International Critical Tables, Vol. II, p. 457. New York: McGraw-Hill Book Co., Inc., 1927.

¹² L. B. Smith and F. G. Keyes, Proc. Am. Acad. Arts and Sci., **69**, 313 (1934).

5. D_2 corrects for the volume of liquid mercury lost by evaporation into the gas space:

$$D_2 = \frac{200.6 \, p_{Hg} m v}{R T d_t}, \quad (13)$$

where p_{Hg} is the vapor pressure of mercury at $T^\circ K$ and under the total pressure p . This correction is negligible for temperatures below $200^\circ C$.

6. D_3 is the correction for the variation with temperature of the volume (2.4 cc.) of mercury in the riser-block, bomb stopcock, and the capillaries at room temperature.

The three corrections, D_1 , D_2 , D_3 , are all very small and can easily be made with a total uncertainty of 0.001 cc. or less.

The calculated volume $V_{p,t}$ can then be translated into a compressor setting which gives the readings for the desired volume. The corrections 3 and 4 depend on the pressure, which at the start of a measurement is unknown. The pressure is estimated and a provisional compressor setting computed. The pressure is then measured and a new setting computed. Since ΔV varies slowly with pressure, and D_1 is very small the calculations converge rapidly, two computations usually being sufficient to obtain the compressor setting to 0.001 turn.

The pressure p_{Gas} exerted by the gas is given by the relation:

$$p_{Gas} = p + p_{Bar} + p_{Level} + p_{Meniscus} - p_{Hg}, \quad (14)$$

where:

1. p is the pressure measured on the dead-weight gauge.
2. p_{Bar} is the corrected barometric pressure.
3. p_{Level} is the correction for the differences in oil-levels and mercury-levels, reduced to normal atmospheres. The oil head is very small and no correction for the effect of temperature and pressure is applied. The mercury head is divided into two sections, one at room temperature, and one at the thermostat temperature, the dividing line being the outer surface of the thermostat top. The mercury level inside of the all-steel bomb is calculated from the sectional area of the bomb; that for the glass liner determined by running out portions of mercury, weighing them, and measuring the distance from the mercury surface to the top of the outside surface. The results were expressed in plots of the distance from the top surface of the steel bomb (or steel-case) to the mercury surface inside of the bomb against the gas volume $m v$.

4. $p_{Meniscus}$ is a correction of 1 mm. for the capillary depression at the oil-mercury surface in the riser-block.

5. p_{Hg} is the vapor pressure of mercury corrected for the effect of pressure by the relation:

$$2.303 RT \log_{10} \frac{p_{Hg}}{p_{oHg}} = V (p_{Gas} - p_{oHg}), \quad (15)$$

where p_{oHg} is the vapor pressure of mercury (from International Critical Tables) and V the molal volume of liquid mercury at $T^\circ K$.

At each temperature the pressure is measured for the series of increasing densities and these results checked by measuring the pressures for the series of decreasing densities.

5. ACCURACY OF THE RESULTS.

Pressure. The pressure gauge can be calibrated in terms of the vapor pressure of liquid carbon dioxide at $0^\circ C$ with an accuracy of 0.004%, which is about the precision in the measurement of a given constant pressure. The use of the same gauge constant up to 500 atmospheres may introduce an error of 0.01 to 0.02% at the higher pressures. The method of obtaining the average temperature of the mercury head in the region of large thermal gradient introduces an uncertainty of 0.5 mm. of mercury when the bomb thermostat is at a high temperature. The overall accuracy of the pressure measurement is from 0.01% in the low pressure, room temperature region of the data, to 0.03% in the high pressure, high temperature region.

Temperature. A given constant temperature can be read with a given platinum resistance thermometer with a precision of $0.002^\circ C$. The deviations of the readings of a single platinum thermometer from the international platinum resistance thermometer scale (*i. e.* the scale founded on the average of the readings of a large number of platinum thermometers) increase above $100^\circ C$ to a maximum of 0.01 to $0.02^\circ C$ at $325^\circ C$.

Volume. The largest uncertainties and those most difficult to estimate are in the measurement of volume. The volumes of mercury forced out by the mercury injector at one atmosphere are known to 0.004 cc. The effect of the temperature of the bomb and of pressure on the apparent volume of the entire system up to the insulated needle is determined in the blank run with an uncertainty of 0.007 cc., and the necessary corrections are either well known (as is the thermal expansion of mercury) or are very small (as are the corrections D_1 , D_2 , and D_3). Yet, due to hysteresis or other effects, we cannot feel sure

of our volumes to better than 0.05% at the higher pressures and temperatures, and quite often the uncertainty is as great as 0.1%.

Mass. There is no difficulty in determining the mass of gas used to 0.2 milligrams.

Total accuracy. The overall uncertainty in the compressibility data obtained by this method increases from 0.03% at the lower pressures and temperatures to 0.1 to 0.2% at the higher pressures and temperatures.

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NEW BANDS OF THE IONIZED NITROGEN MOLECULE.

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THE bands emitted by the ionized nitrogen molecule (assigned to a ${}^2\Sigma \rightarrow {}^2\Sigma$ transition) have been studied by a number of observers under a wide variety of conditions. The sources of most value, however, have been direct current discharges with a hollow cathode,¹ the electrodeless discharge² or high voltage discharges either in pure N_2 or with the addition of small amounts of helium.³ In addition Childs⁴ has used a direct current arc between tungsten electrodes—a source which develops very high rotational lines but gives only a very few vibrational transitions.

EXPERIMENTAL METHODS.

The writers, experimenting with the slotted cathode designed by Frerichs, found that under certain conditions of operation great freedom from the usually very troublesome second positive bands of the neutral molecule resulted. The source consisted briefly of two heavy water-cooled electrodes, the cathode containing a transverse slot from which brilliant emission of the N_2^+ bands resulted at pressures of a few hundredths of a millimeter of mercury. It was found advantageous to replace the block-tin cathode by one of iron, since this permitted heavier currents (around .75 ampere with 400 volts drop across the tube), and, in addition, developed a few very faint and narrow iron lines. These were not sufficiently numerous to cause serious trouble when superposed on the band lines, and yet offered a delicate method of proving the absence of any accidental shifts of the band lines with respect to the iron standards placed on the plates before and after each nitrogen exposure.

A number of cathode-slit widths from around 2 to 5 mm. were employed, and in each case the pressure of the nitrogen was reduced to

¹ Fassbender, *Zeits. f. Physik* **30**, 73 (1924); Frerichs, *ibid.* **35**, 683 (1926); Ornstein and van Wijk, *ibid.* **49**, 315 (1928); Coster and Brons, *ibid.* **73**, 747 (1932).

² Herzberg, *Ann. der Physik* **86**, 189 (1928).

³ Merton and Pilley, *Phil. Mag.* **50**, 195 (1925); Parker, *Phys. Rev.* **44**, 90, 914 (1933).

⁴ Childs, *Proc. Roy. Soc. (A)* **137**, 641 (1932).

such a value that the discharge was unstable, being almost ready to break over into a diffuse and feeble glow discharge with no visible emission from the slit in the cathode. Since the greatest freedom from the troublesome bands of N_2 resulted under these conditions, it was necessary to watch the discharge quite closely since a few minutes' discharge at a higher pressure would ruin the most desired bands by superposition of strong N_2 bands. It was found that, when the electrode from a small induction coil (such as that used for leak-testing purposes) was placed near enough the glass bulb containing the discharge to allow a continuous sparking to the glass, much more steady operation resulted. This was particularly useful in the longest exposures, which were made in the first (and where possible the second) order of a 21-foot grating giving a dispersion of 1 Å/mm. in the second order. The exposures ran from 2 to 28 hours in length. Eastman "33" plates were used for the first order, "50's" for the second, and the "3G" plates for all green regions. The usual iron comparisons were made with an arc of the Bureau of Standards specifications,⁵ the standard lines used being those recommended by the International Astronomical Union.⁶ The plates were measured to .001 mm and in the second order plates and the R branches where overlapping is least the results are dependable to less than $\pm .005$ Å. Near the origins, however, and at the heads the uncertainty is hard to estimate, but is certainly greater.

RESULTS.

This source developed the $\Delta v = 0, +1$ and $+2$ sequences quite intensely, and gave the first three members of the $\Delta v = +3$ sequence with usable intensity and very high purity. The freedom from appreciable overlapping of N_2 bands has enabled the rotational fine structure of the following bands to be determined (2-2) $\lambda 3858$, (3-4) $\lambda 4166.8-4166.4$, (5-7) $\lambda 4486$, (6-8) $\lambda 4466.6$, (0-3) $\lambda 5228$, (1-4) $\lambda 5148.8$, and (2-5) $\lambda 5076.5$. The (3-4) band was particularly important, since Coster and Brons were not able to follow the (3-5) band below $K = 4$ and settle the question as to the precise extent of the perturbation of the $v' = 3$ level and the proper assignment of spin doublet components. New data on this band is also included. A few lines of the (3-6) band were observed but were not strong enough to be of much value in the analysis.

⁵ Meggers, Kiess and Burns, Bull. Bureau of Stds, 19, 263 (1923-4).

⁶ Trans. Int. Astron. Union III, 84 (1928).

The rotational assignments of the new bands and the vacuum frequencies are given in Table I. The frequencies of the origins were determined graphically from the first half dozen or so lines of each branch and are compared with those computed from the origin formula of Coster and Brons in Table IV. Except in bands involving the perturbed upper levels $v' = 1$, $v' = 3$, and $v' = 5$, the spin doubling was resolved only for the higher rotational lines where theoretically the spin members should be almost equally intense. In the perturbed bands involving $v' = 1$ and $v' = 5$ only one level is perturbed, and the fact that the perturbed members of each doublet to the *low* frequency *before* the perturbation and to the *high* frequency *above* this point are definitely more intense shows these to have originated on the $T_1(K + \frac{1}{2})$ levels. Accordingly, to save space, the $R_1(K)$, $R_2(K)$ and $P_1(K)$ and $P_2(K)$ lines are listed under their common K value. The R_1 and P_1 lines are in every case listed *above* the R_2 and P_2 lines, where of course the former are of lower frequency *before*, and of higher frequency than the latter *after* the perturbation. For convenience the most perturbed lines immediately before and immediately after the perturbation are designated by an asterisk. Where three lines are entered for a single K value, the central one is the T_2 line and the outer ones the T_1 lines. The corresponding double differences $\Delta_2 T'$ and $\Delta_2 T''$ are given, respectively, in Tables II and III with the same convention employed, where for purposes of comparison the corresponding values from other bands, as remeasured by us, are included. Where we have observed only one band involving a given level, comparison values are given from Parker and from Coster and Brons.

In the analysis of the (1-4) $\lambda 5148.8$ band, which was so nearly free from impurities that almost every measurable line on the plate was assigned a place in the band, it was found impossible to obtain agreement with the $\Delta_2 T'_1(K)$ values given by Coster and Brons for the lines $K = 13$ and $K = 14$. Accordingly the three bands (1-1) (1-2) and (1-3) were completely remeasured, with the result that a natural assignment of lines was discovered which agreed well with the $\lambda 5148.8$ band and at the same time gave a more nearly regular set of $\Delta_2 T'_1(K)$ values for $v' = 1$. Since the corresponding $\Delta_2 T''(K)$ values agreed quite satisfactorily with the 4 independent sets of values from other bands, the agreement can hardly be accidental. In Table I-A these branch assignments and frequencies for the K values near the point in question are recorded. In addition the values of $\Delta_2 T'_1(K) / (4K + 2)$

are computed for each K value and may be compared with the average value computed from the data of Coster and Brons (Column I) from the (1-2) and (1-3) bands. The sudden and irregular increase at $K = 13$ and 14 is seen to be replaced by fluctuations which must be regarded as entirely random.

The great reduction of overlapping N_2 bands on the best plates has also permitted us to analyze the (3-4) band and to extend the analysis

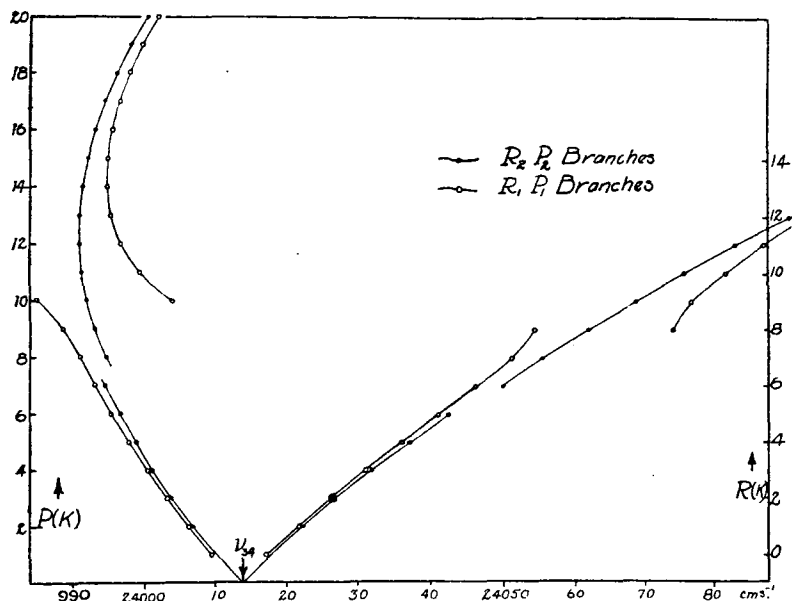


FIGURE 1. Fortrat Diagram of the (3-4) $\lambda 4166.8-.4$ band showing the double perturbation, the more violent of which is responsible for the formation of the double P branch which results in the double headed appearance so characteristic of low dispersion photographs.

of the (3-5) band to the origin. The results indicate, as found earlier by Coster and Brons, that both spin levels are perturbed, the $T_1(K + \frac{1}{2})$ levels (the reasons for the assignment are considered below) suffering a very large perturbation (maximum shift about 11 cm^{-1}) centering around $K' = 9$, while the $T_2(K - \frac{1}{2})$ levels suffer a much smaller perturbation (maximum shift about 1 cm^{-1}) centering between $K' = 6$ and $K' = 7$. Although Coster and Brons

suggested the possibility of a further perturbation nearer the origin, we have found no definite evidence for it. The early lines do seem to be abnormally low in intensity but fall quite smoothly on the normal Fortrat curves. (See Fig. 1.)

The rotational constants B'_v and B''_v have been computed from the double differences given in Tables II and III. Where only one level is perturbed the other has been used for this purpose. Where both are perturbed a curve with smoothly turning tangent was drawn through the regions of perturbation and B -values computed from this. If we write

$$\Delta T(K) = (4K + 2) [B_v + 2D_v(K^2 + K + 1) + \dots]$$

the values of $\Delta T(K) / (4K + 2)$ should give sensibly B_v as long as D_v is so small as to make no appreciable contributions. But as D_v' is of the order of 4.3×10^{-6} and D_v'' is smaller we see that, even for $K = 8$, the contributions of this term can hardly be expected to affect the value of $\Delta T(K) / (4K + 2)$ in the third decimal. Hence fluctuations of this quantity for $K \leq 8$ must be regarded as due to experimental uncertainties or the residual effects of perturbations. Hence average values for the first 8 members of each set were taken as the true B_v values. The values so determined are compared in Table V with the calculated values obtained from the empirical expressions given by Coster and Brons and by Parker.

PERTURBATIONS.

The previous designation⁷ of the perturbed levels in the $v' = 1$ and $v' = 5$ state as T_1 levels (*i. e.* belonging to levels with $J = K + \frac{1}{2}$) is completely in agreement with our results. The situation is, however, much more complicated in bands involving the $v' = 3$ level, and it is unfortunate that only the (3-4) and (3-5) bands could be observed.

Since in a normal spin doublet the member involving the T_1 level is stronger than that involving the T_2 level in the ratio of $K + 1/K$, provided the perturbation does not too much modify the normal intensity distribution, the determination of which component is more intense on either side of and sufficiently far from the perturbation should settle the question of assignment. For this purpose densitometer records were made from both first and second order plates on a recording thermocouple densitometer constructed by one of us (F.H.C.). In use a linear magnification of about 50 : 1 was employed

⁷ *Loc. cit.* Refs. 1 and 3.

and, in order to avoid as much as possible irregularities due to plate grain, dust, scratches on the emulsion, etc., the thermocouple was adjusted so as to integrate the light from a narrow illuminated strip on the plate, which never covered less than 5 or 6 mm. of the length

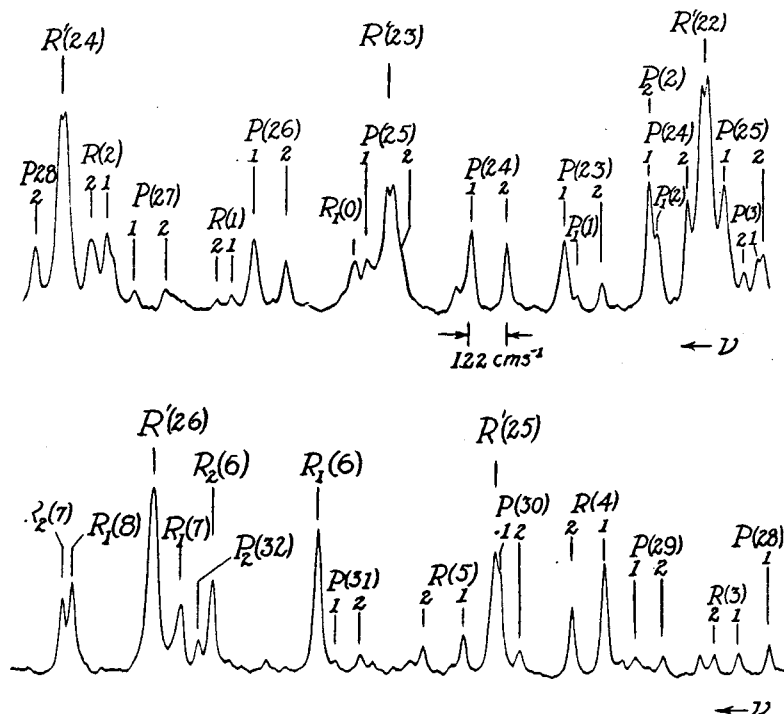


FIGURE 2. Microphotometer record of a portion of the (3-4) $\lambda 4166.8-.4$ band where the lines not marked are of spurious origin. The perturbation in the R_2 lines reaches its maximum between $R_2(5)$ and $R_2(6)$ while that of the R_1 lines is near $R_1(8)$ at the edge of the figure. The two portions are continuous records beginning in the upper right hand corner and continuing to the lower left hand corner. The primed R lines belong to the overlapping (2-3) band. The freedom from extraneous N_2 lines is striking.

of a line. The resolving power was sufficient to indicate any line structure which could be seen on a direct 15-fold enlargement made from the original plate with contrast paper and gave definite reproducible recordings of lines so faint that they had earlier been

measured on a visual comparator but marked doubtful. In the case of the (3-4) band the early R -lines, $R(1)$, $R(2)$, $R(3)$, $R(4)$, $R(5)$ and $R(6)$ all showed the $-$ component⁸ definitely stronger, though the difference was very slight except for $R(4)$ and $R(5)$, and the $R(2)$ doublet certainly involves some superposition. Above the perturbation the $+$ components are fainter than the $-$ but gradually increase in intensity, becoming almost identical at $R(14)$ and definitely stronger for $R(17)$. Above this point the (4-5) band intervenes and prevents further observation. Unfortunately, the early P lines are in much too crowded a region to allow accurate densitometry. Of the favorably located higher ones, $P(23)$, $P(24)$, and $P(26)$ have the $+$ component stronger and only $P(28)$ shows the reverse. $P(28)$ is quite close to $R(24)$ of the (2-3) band. (See Fig. 2.) The intensity asymmetry of these high P lines is rather greater than one would expect for such high K values.

The results in the case of the (3-5) band are slightly less decisive. Here, as in the (3-4) band, the $-$ component is more intense for $R(1)$ and $R(4)$ while $R(6) +$ and $R(6) -$ are of almost identical intensity. In the case of $R(5)$, on the other hand, the $-$ component is definitely weaker. This may possibly be due to superposition, since $R(5) +$ is nearly as intense as $R(4) -$ and $R(6) -$, a fact not in harmony with the usual regular alternating intensity. The other early R lines are all unfavorably situated. Above the perturbation $R(16)$, $R(18)$, $R(20)$, $R(25)$, and $R(27)$ [the (4-6) band obscures the others above $R(20)$] show the $+$ component stronger, while $R(15)$, $R(17)$ and $R(19)$ show the reverse. Of the P lines which are in the open we find $P(20)$, $P(22)$, $P(24)$, $P(26)$, and $P(29)$ with the $+$ component stronger, while $P(21)$ and $P(25)$ show the reverse. These results, then, seem to point fairly conclusively to the inference that the largely perturbed lines of the $v' = 3$ level originate on $T_1(K + \frac{1}{2})$ levels rather than on $T_2(K - \frac{1}{2})$ levels, as Coster and Brons concluded. It should be emphasized that they based their inference entirely on the (3-5) band—where the evidence is less unambiguous than for the (3-4) band. The rather small asymmetry of the $R(1)$, $R(2)$, and $R(3)$ lines is possibly accounted for by the following considerations. Suppose we regard the early $T_1(K + \frac{1}{2})$ levels as being perturbed below their corresponding $T_2(K - \frac{1}{2})$ levels in the $v' = 3$ state, while for the $v'' = 4$ and $v'' = 5$ states they are of course almost

⁸ For brevity the high frequency member of a pair or group will be called the $+$ and the low frequency the $-$ component.

indistinguishably close to them (see Fig. 3). Then the fragmentary Q branch, which should be more intense at the origin and rapidly vanish in intensity with K , involves transitions such that, for example, with $\Delta J = 0$ and $\Delta K = -1$ the corresponding ${}^RQ_{21}(K)$ line will practically coincide with $R_2(K)$. But $R_2(K)$ is by our hypothesis the $+$ component for low K values and should therefore have a slightly enhanced intensity, thus tending to make the $R(K)$ doublets more nearly symmetrical in intensity than otherwise. If we suppose

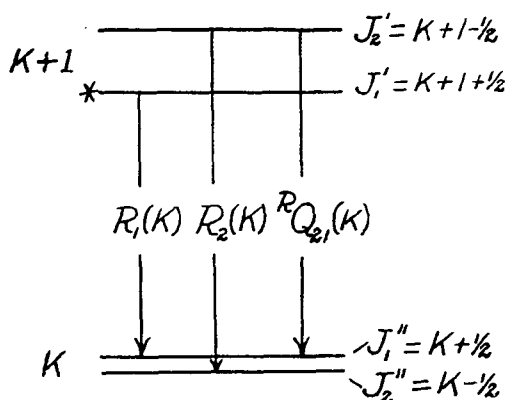


FIGURE 3. Transitions giving R and ${}^RQ$ branch lines before the main perturbation, in which case the perturbed level (*) in the upper ${}^2\Sigma$ state lies below the $T_2(K - 1/2)$ level. If the perturbed level were called a T_2 level, the $-$ component of an R doublet would be enhanced.

the lower spin level of the upper ${}^2\Sigma$ state is T_2 level then the ${}^RQ_{21}(K)$ line will fall on the $R_1(K)$ line and produce greater asymmetry than otherwise. This certainly seems contrary to our observations.

As a result, in disagreement with Coster and Brons, we have identified the $v' = 3$ rotational spin sub-levels with the major perturbation as T_1 levels and have so arranged the data in the tables. It must be pointed out, however, that the accidental superposition of faint and unsuspected lines, together with a disturbance of normal intensity considerations, may invalidate the above reasoning. Statistically the former possibility seems extremely unlikely—while at points sufficiently remote from the perturbation (and, due to its asymmetry, it should affect the intensity of the perturbed lines for a

longer distance above than below the displacement maximum, see Fig. 4) we should certainly find the usual criteria applying.

To represent the course of the perturbation of the $v' = 3$ levels when both the T_1 and T_2 levels are disturbed, it is necessary to pass as smooth a curve as possible through the less perturbed lines and then

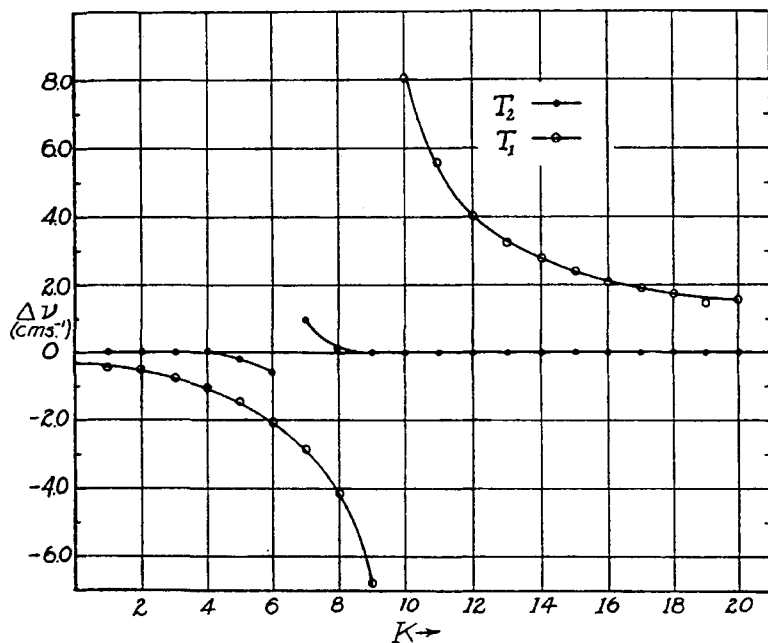


FIGURE 4. Actual displacements of the $T_1'(K + \frac{1}{2})$ and $T_2'(K - \frac{1}{2})$ levels from their smoothed values plotted against initial quantum number for the (3-5) $\lambda 4554.4-.2$ band. See Table VI.

determine the frequency shift of the observed lines from this. In Table VI under "smoothed values," columns II and VII, are given these values for the R and P branches of the (3-5) band. They actually form a continuous set, as the regular progression of the first differences shows. The values of $R_1(K) - R_{\text{smoothed}}$, $P_1(K) - P_{\text{smoothed}}$, $R_2(K) - R_{\text{smoothed}}$, and $P_2(K) - P_{\text{smoothed}}$, are then given in columns X, XI, XII and XIII, respectively. Since the rows in Table VI are arranged according to common *initial* K values, the rows of X and

XI and of XII and XIII may be averaged directly. The results are shown graphically as a function of K' in Fig. 4.

In order to compare with these the results from the (3-4) band, it is possible to repeat the above process, though we have chosen to smooth the double differences, $\Delta_2 T'(K)$, and represent the departures

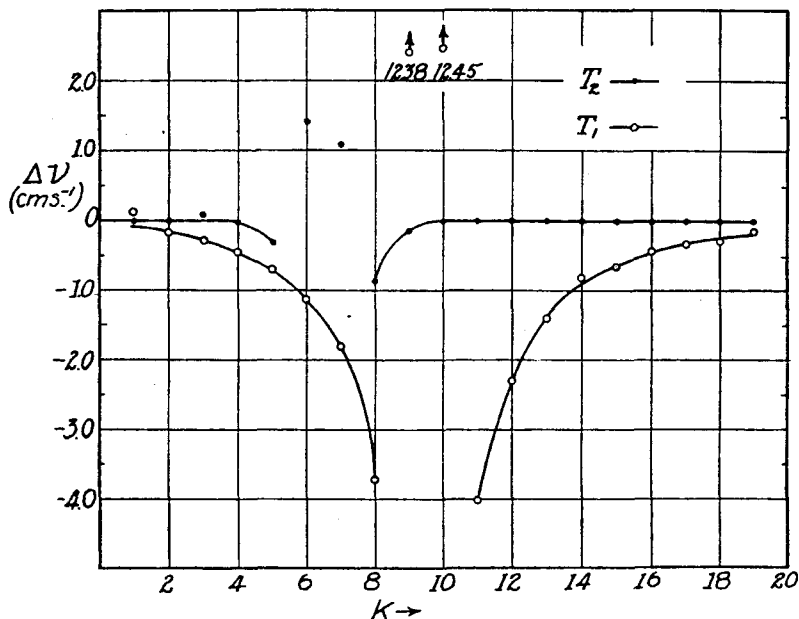


FIGURE 5. Graph showing the departures from smoothed $\Delta_2 T'$ values of the observed $\Delta_2 T_1'$ and $\Delta_2 T_2'$ values for $v' = 3$ as averaged from the (3-4) and (3-5) bands. Here negative values indicate closer spacing of the rotational levels, and positive values wider spacing than the normal.

of the observed values, $\Delta_2 T_1'(K)$ and $\Delta_2 T_2'(K)$, from these for the two bands. The results are given in Table VII and graphed in Fig. 5. The gradual increase of crowding of the rotational levels as the perturbation is approached, is shown by the rapid falling of the curves, while their gradual spreading out to the normal separation above the perturbation is indicated by the subsequent rise after the break. The two isolated positive points in each case arise from the fact that the separations of levels just above from those just below the perturbation are being measured. Since they represent the

absolute value of the *deficit* of height of a rotational level *below* and of the *excess* height of another (2 units of K' higher) *above* the perturbation, they must be above the axis. Since the perturbing state is presumably a $^2\Pi$ state, we infer that one member perturbs the T_1 levels violently near $K' = 9$ and $K' = 10$ while the other affects the T_1 levels less strongly, the center of perturbation being between $K' = 6$ and $K' = 7$.

In conclusion, we wish to express our indebtedness to the Rumford Fund of the American Academy for a generous grant used in the construction of the densitometer employed in this work. It is also a pleasure to express our obligation to Mrs. Kyung J. S. Tsai for her valuable assistance in the computation and checking of numerical results.

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TABLE I.
ROTATIONAL FREQUENCIES.

(2-2) $\lambda 3857.9$ Band. $\nu_{22} = 25939.85 \text{ cm}^{-1}$

<i>K</i>	<i>R</i> Branch	<i>P</i> Branch	<i>K</i>	<i>R</i> Branch	<i>P</i> Branch
0	25943.74	—	16	26047.55	25914.01
1	47.98	25935.76	17	56.25	14.86
2	52.71	32.48	18	65.41	15.95
3	57.50	29.30	19	74.89	17.00
4	62.88	26.16	20	84.58	18.66
5	68.25	23.78			
6	74.08	21.36	21	94.43	20.77
7	80.14	19.34	22	104.83	—
8	86.57	17.49	23	15.39	—
9	93.17	15.95	24	25.96	—
10	26000.00	14.86	25	37.19	—
11	07.31	14.01	26	48.46	—
12	14.68	13.55	27	60.25	—
13	22.48	13.13	28	71.69	—
14	30.51	13.13	29	83.87	—
15	38.97	13.55	30	96.04	—
			31	208.52	—
			32	20.97	—

(3-4) $\lambda 4166.8-.4$ $\nu_{34} = 24013.90 \text{ cm}^{-1}$

0	24017.48	—	7	24051.20*	23993.18
1	21.84	24009.55		55.50	94.43
	22.80	—	8	55.20*	91.05*
2	26.38	06.45		61.91	94.73
	26.98	06.95		74.17*	—
3	31.14	03.33	9	76.77*	88.50*
	31.98	03.80		68.70	92.88
4	36.06	00.48	10	81.84	85.00*
	37.23	01.15		75.81	91.89
5	41.20	23997.88		—	04.09*
	42.57	98.80			
6	46.30	95.49	11	87.29	99.40*
	50.04	96.61		83.18	91.48

* Perturbed lines near maximum of perturbation.

TABLE I.—ROTATIONAL FREQUENCIES—(Continued).

(3-4) $\lambda 4166.8-.4$ $\nu_{34} = 24013.90 \text{ cm}^{-1}$ —(Continued).

<i>K</i>	<i>R</i> Branch	<i>P</i> Branch	<i>K</i>	<i>R</i> Branch	<i>P</i> Branch
12	24094.19	23996.61	19	24155.10	23999.70
	90.88	91.05		—	97.88
13	24101.72	95.23	20	65.15	24001.87
	098.91	91.05		63.79	00.48
14	109.73	94.73			
	107.32	91.48	21	75.47	04.09
15	17.87	94.73		74.20	02.63
	15.97	92.14	22	86.22	06.95
				84.89	05.51
16	24126.83	23995.49	23	—	10.05
	24.91	93.18		—	08.65
17	35.92	96.61	24	208.49	13.36
	34.16	94.43		207.30	12.14
18	45.28	97.88			
	43.79	96.05			

(3-5) $\lambda 4554.4-.2$ $\nu_{35} = 21970.9 \text{ cm}^{-1}$

0	21974.49	0	—	9	22035.36*	9	21946.99*
1	78.74	1	21966.60†		27.26		51.41
	79.26		—	10	40.36*	10	43.98*
2	83.14	2	63.34		34.72		50.82
	83.82		63.77		—		63.13*
3	88.17	3	60.44	11	46.71	11	58.83*
	89.11		60.90		42.90		50.82
4	93.30	4	57.66	12	54.11	12	56.42*
	94.50		58.39		50.87		50.82
5	98.62	5	55.26	13	62.19	13	55.63
	22000.06		56.42		59.42		51.41
6	03.97	6	53.02	14	70.79	14	55.63
	07.74		54.27		68.31		52.40
7	09.18*	7	50.82	15	79.55	15	56.42
	13.51		52.40		77.50		53.61
8	13.51*	8	49.18*	16	88.96	16	57.66
	20.09		53.02		87.06		55.26
	32.41*		—				

* Perturbed lines near maximum of perturbation.

† Superposed by another line.

TABLE I.—ROTATIONAL FREQUENCIES—(Continued).
 (3-5) $\lambda 4554.4-2$ $\nu_{35} = 21970.9 \text{ cm}^{-1}$ —(Continued).

<i>K</i>	<i>R</i> Branch	<i>P</i> Branch	<i>K</i>	<i>R</i> Branch	<i>P</i> Branch
17	22098.73	17 21959.35	23	22164.90	21977.65
	96.94	57.27		63.71	76.28
18	22108.85	18 61.47	24	77.16	82.04
	07.25	59.57		76.06	80.77
19	19.42	19 63.96	25	89.69	86.67
	17.84	62.28		88.60	85.38
20	30.34	20 66.60†			
	28.83	65.23	26	22202.63	
21	41.67	21 70.10		01.50	
	40.27	68.51	27	15.80	
22	53.01	22 73.75		14.93	
	51.82	72.25	28	29.41	
				28.42	

(5-7) $\lambda 4486$ $\nu_{57} = 22307.5 \text{ cm}^{-1}$					
0	—	—	10	22368.51	22287.54
1	—	—		366.26	284.92
	—	—			
2	22318.68	22299.58	11	375.60	286.78
	19.96	300.38		373.48	284.31
3	321.40*	297.28	12	383.01	286.50
	324.36	297.61		381.10	284.31
	330.62*	—	13	390.75	286.50
4	322.81*	93.98*		389.01	284.31
	329.36	95.13	14	398.83	286.78
	332.99*	—		397.22	284.92
5	—	289.48*	15	407.13	287.16
	334.41	292.36		405.60	285.59
	337.90*	298.63*			
6	343.38*	293.98*	16	415.78	288.29
	340.36	290.07		414.35	286.50
7	349.27	291.61	17	424.77	289.48
	346.32	288.29		423.30	287.54
8	355.28	290.07	18	434.07	291.13
	352.68	286.78		432.75	289.48
9	361.77	288.48	19	443.94	292.94
	359.25	285.59		442.26	291.61
			20	453.51	295.13
				452.35	293.98

* Perturbed lines near maximum of perturbation.

† Superposed by another line.

TABLE I.—ROTATIONAL FREQUENCIES—(Continued).

(5-7) $\lambda 4486$ $\nu_{57} = 22307.5 \text{ cm}^{-1}$ —(Continued.)

<i>K</i>	<i>R</i> Branch	<i>P</i> Branch	<i>K</i>	<i>R</i> Branch	<i>P</i> Branch
21	—	—	23	—	22303.65
22	22474.19	22300.92		—	302.52
	472.80	299.58	24	22495.98	307.08
				494.99	305.87

(6-8) $\lambda 4466.6$ $\nu_{68} = 22406.55 \text{ cm}^{-1}$

0	22410.23	—	14	22492.15	22382.10
1	14.35	22402.98	15	99.76	82.10
2	18.67	399.62			
3	23.30	96.67	16	507.77	82.36
4	28.22	94.03		.95	—
5	33.36	91.45	17	16.37	83.49
			18	24.87	84.81
6	38.84	89.01		25.23	—
7	44.60	87.43	19	33.66	85.91
8	50.54	85.91		34.12	—
9	56.77	84.63	20	42.80	87.43
10	63.29	83.49		43.15	87.64
11	70.11	82.77	21	52.28†	89.78
12	77.29	82.36		53.28†	—
13	84.45	82.10			

(0-3) $\lambda 5228.3$ $\nu_{03} = 19139.7 \text{ cm}^{-1}$

0	19143.73	—	11	19217.09	19121.63
1	48.30	19136.08	12	26.30	22.49
2	53.32	32.52	13	35.92	23.83
3	58.74	29.71	14	45.89	25.42
4	64.55	27.16	15	56.28	27.78
5	70.81	25.42			
			16	67.27	30.37
6	77.47	23.58	17	78.30	33.25
7	84.56	22.49	18	89.81	36.65
8	92.06	21.65		90.04	—
9	19200.00	21.26	19	19301.87	40.47
10	08.36	21.26		02.02	—
			20	14.39	44.76
				14.53	—

† Edges of broad band.

TABLE I.—ROTATIONAL FREQUENCIES—(Continued).

(0-3) $\lambda 5228.3$ $\nu_{03} = 19139.7 \text{ cm}^{-1}$ —(Continued).

<i>K</i>	<i>R</i> Branch	<i>P</i> Branch	<i>K</i>	<i>R</i> Branch	<i>P</i> Branch
21	19327.15	19149.46	25		19172.21
	27.53				72.50
22	40.52	54.49	26		79.05
	40.98	54.74			79.37
23	54.20	59.97	27		86.19
	54.68	60.21			86.51
24	68.42	65.85	28		93.82
	68.81	66.16			94.24

(1-4) $\lambda 5148.8$ $\nu_{14} = 19434.75 \text{ cm}^{-1}$

0	19439.00	—	15	19551.41	19426.64*
1	—	19430.95		49.81	22.81
2	48.53	(27.95)	16	61.93	27.71*
3	53.72	25.33		60.52	25.33
4	59.53	22.59	17	72.96	29.88
5	65.81	20.73		71.54	28.20
6	72.20	18.98	18		32.94
7	79.11	17.76			31.61
8	86.51	16.90	19		36.46
9	93.98	16.44			35.34
	94.38		20		40.58
10	01.97	16.44			39.50
	19502.64		21		45.02
11	09.58*	16.90			44.08
	11.21		22		50.00
12	16.23*	16.90			49.07
	20.29	17.76	23		55.25
13	33.45*	17.33*			54.45
	29.70	18.98	24		62.00
14	41.80*	16.44*			61.10
	39.56	20.73			

Values in parentheses are interpolated graphically.

TABLE I.—ROTATIONAL FREQUENCIES—(Continued).

(2- ϵ) $\lambda 5076.5$ $\nu_{25} = 19710.4 \text{ cm}^{-1}$

K	R Branch	P Branch	K	R Branch	P Branch
0	(19714.53)	—	11	19785.64	19692.70
1	19718.93	19706.67	12	94.58	93.46
2	23.94	03.63	13	(803.91)	94.69
3	29.23*	00.61	14	19813.43	96.24
4	34.95	19698.19	15	(823.44)	98.19
5	41.01	96.24			
			16	34.00	19700.61
6	47.39	94.69	17	(844.87)	03.63
7	54.17	93.46	18	56.01	706.67
8	61.53	92.70	19	(867.68)	710.12
9	69.18	92.26	20	79.68	13.71
10	76.56	92.26			
			21	92.12	18.26
			22	905.08	23.22

Values in parentheses are interpolated graphically.

TABLE I-A.

C and B $\frac{\Delta_2 T''}{(4K+2)}$	(1-1) $\lambda 3884$			(1-2) $\lambda 4236.5$			(1-3) $\lambda 4651.9$		
	K	R	P	R	P	$\frac{\Delta_2 T''}{(4K+2)}$	R	P	$\frac{\Delta_2 T''}{(4K+2)}$
2.0486	11	25830.30*	25736.99*	23690.53*	23597.75*	2.0463	21583.55	21490.33*	2.0421
		31.71	37.37	692.04	97.91		85.11	91.17	
2.0500	12	35.41*	36.06*	696.05	97.17*	2.0478	89.69	90.33*	2.0516
		39.41	36.99	23700.14	97.75		93.75	91.17	
2.0794	13	—	35.01*	712.52	96.39*	2.0492	06.41	90.33*	2.0498
		47.34	36.50	708.57	97.91		02.54	91.85	
2.1196	14	57.83*	32.57*	19.75	94.45*	2.0486	14.09	88.97*	2.0508
		55.62	36.77	17.38	98.56		11.90	92.95	
2.0490	15	65.79*	40.88*	28.15	23603.31*	2.0483	23.23	98.56*	2.0462
		64.11	36.99	26.50	599.50		21.54	94.67	
2.0484	16	74.32	39.90	37.27	602.96	2.0476	32.96	98.56*	
		72.75	37.37	35.93	00.79		31.62	96.44	2.0481

TABLE II.
 $\Delta_2 T'(K)$ VALUES

$v' = 0$			$v' = 1$				
K	Average†	$\lambda 5228.3$	K	(1-1)	(1-2)	(1-3)	(1-4)
1	12.39	12.22	1	12.62	12.49	12.66	12.26
2	20.77	20.80	2	20.53	20.55	20.72	20.58
3	29.02	29.03	3	28.80	28.63	28.74	28.39
4	37.37	37.39	4	37.13	37.30	37.10	36.94
5	45.56	45.39	5	45.13	45.28	45.00	45.08
6	54.02	53.89	6	53.20	53.27	53.15	53.22
7	62.18	62.07	7	61.34	61.50	61.56	61.35
8	70.48	70.41	8	69.55	69.74	69.70	69.61
9	78.81	78.74	9	77.82	77.76	77.67	77.74
10	87.15	87.10	10	85.70	85.63	85.36	85.53
11	95.46	95.44	11	93.31	92.78	93.22	
12	103.56	103.81		94.34	94.13	93.94	(93.50) ⁺
13	112.04	112.09	12	99.35	98.88	99.35	99.33
14	120.36	120.47		102.42	102.39	102.58	102.53
15	128.50	128.50	13	—	116.13	116.08	116.12
16	136.733	136.90		110.84	110.66	110.69	110.72
	.600	—	14	125.26	125.30	125.12	125.36
17	144.960	145.05		118.85	118.82	118.95	118.83
	.910	—	15	124.91	124.84	124.67	124.77
18	153.170	153.28		127.12	127.00	126.87	127.00
	.150	—	16	134.42	134.31	134.40	134.22
19	161.443	161.48		135.38	135.14	135.18	135.19
	.350	—	17	142.90	142.82	142.89	143.08
20	169.69	169.70		143.73	143.26	143.52	143.34
	.69	—	18	150.95	151.13	151.27	—
21	177.88	177.88		151.43	151.47	151.53	—
	.88						
22	186.06	186.03					
	.15	.24					
23	194.30	194.23					
	.36	.47					
24	202.57	202.57					
	.54	.65					

†Av. from $\lambda\lambda 3914, 4278, 4709$ and 5228 .
() calculated values.
⁺Average of $\Delta_2 T_1'$ and $\Delta_2 T_2'$ values.

TABLE II.—(Continued).

 $\Delta_2 T'(K)$ VALUES $v' = 2$

K	(2-2) 3857.9	(2-3) 4199.2	(2-4) 4599.9	(2-5) 5076.5
1	12.22	12.05	12.20	12.26
2	20.23	20.18	19.94	20.31
3	28.20	28.20	28.42	28.62
4	36.72	36.35	36.51	36.76
5	44.47	44.57	44.59	44.77
6	52.72	52.59	52.67	52.70
7	60.80	60.67	60.95	60.71
8	69.08	68.80	68.85	68.82
9	77.22	76.91	77.27	76.92
10	85.14	84.99	84.97	84.30
11	93.30	93.20	93.06	92.94
12	101.13	101.11	101.35	101.12
13	109.35	109.37	108.98	109.22
14	117.38	117.35	117.11	117.19
15	125.42	125.46	125.30	125.25
16	133.54	133.53	133.81	133.39
17	141.39	141.52	141.45	141.24
18	149.46	149.62	148.87	149.34
19	157.89	157.71	157.53	(157.56)
20	165.92	165.50	165.64	165.97
21	173.66	173.71	173.80	(173.86)
22		181.75	181.92	181.86
23		189.73	189.67	
24			197.68	
25			205.89	
26			213.81	
27			221.38	
28			228.79	
29			237.17	
30			245.78	
31			254.02	
32			261.59	

TABLE II.—(Continued).

 $\Delta_2 T'(K)$ VALUES $v' = 3$

K	(3-4)	(3-5)	K	(3-4)	(3-5)
	4166.8 4166.4	4554.4 4553.2		4166.8 4166.4	4554.4 4553.2
1	12.29 —	12.14 —	14	115.00 115.84	115.16 115.91
2	19.93 20.03	19.80 20.05	15	123.14 123.83	123.13 123.89
3	27.81 28.18	27.73 28.21	16	131.34 131.73	131.30 131.80
4	35.58 36.08	35.64 36.11	17	139.31 139.73	139.38 139.67
5	43.32 43.77	43.36 43.64	18	147.40 147.74	147.38 147.68
6	50.81 53.43	50.95 53.47	19	155.40 —	155.46 155.56
7	58.02 61.07	58.36 61.11	20	163.28 163.22	163.74 163.60
8	64.15 67.18	64.33 67.07	21	171.38 171.57	171.57 171.76
9	88.27 75.82	88.37 75.85	22	179.27 179.38	179.26 179.57
10	96.84 83.92	96.38 83.90	23	187.02 187.34	187.25 187.43
11	87.89 91.70	87.88 92.08	24	195.13 195.16	195.12 195.29
12	97.58 99.83	97.69 100.05	25	— —	203.02 203.22
13	106.49 107.86	106.56 108.01	26	210.93 211.02	— —

TABLE II.—(Continued).
 $\Delta_2 T''(K)$ VALUES
 $v' = 5$

<i>K</i>	Parker†	(5-7) $\lambda 4486$	<i>K</i>	Parker†	(5-7) $\lambda 4486$
1	—	—	13	104.56	104.25
	—	—		—	104.70
2	—	19.10*	14	—	112.05
	—	19.58		—	112.30
3	—	24.12*	15	120.07	119.97
	25.16	26.75		—	120.01
4	—	28.83*			
	34.01	34.23	16	—	127.49
5	42.41	—*		—	127.85
	—	42.05	17	—	135.29
	—	39.27*		—	135.76
			18	—	142.94
6	50.23	49.40*		—	143.27
	—	50.29	19	—	151.00
7	—	57.66		—	150.65
	—	58.03	20	—	158.38
8	65.73	65.21		—	158.37
	—	65.90			
9	73.73	73.29	21	—	—
	—	73.66		—	—
10	81.36	80.97	22	—	173.27
	—	81.34		—	173.22
			23	—	—
11	89.04	88.82		—	—
	—	89.17	24	—	188.90
12	97.10	96.51		—	189.12
	—	96.79			

† Values from 5-8 band.
* Perturbed lines immediately before and after point of greatest displacement.

TABLE II.—(Continued).

 $\Delta_2 T'(K)$ VALUES $v' = 6$

K	Parker*	(6-8) $\lambda 4466.6$	K	Parker*	(6-8) $\lambda 4466.6$
1	11.10	11.37	11	—	87.34
2	17.85	19.03	12	94.99	94.93
3	—	26.63	13	102.90	102.35
4	34.28	34.19	14	110.10	110.05
5	42.08	41.91	15	117.57	117.66
6	49.69	49.83	16	125.28	125.46
7	57.27	57.17	17	132.72	132.88
8	64.71	64.63	18	140.01	140.24
9	72.27	72.14	19	—	147.98
10	80.19	79.80	20	—	155.34
			21	—	163.00

TABLE III.

 $\Delta_2 T''(K)$ VALUES $v'' = 2$

K	Average†	(2-2) $\lambda 3857.9$	K	Average†	(2-2) $\lambda 3857.9$
1	11.30	11.26	11	86.63	86.45
2	18.74	18.68	12	94.19	94.18
3	26.34	26.55	13	101.64	101.55
4	33.96	33.72	14	109.26	108.93
5	41.54	41.52	15	116.70	116.50
6	49.00	48.91	16	124.15	124.11
7	56.51	56.59	17	131.59	131.60
8	64.07	64.19	18	139.10	139.25
9	71.58	71.71	19	146.55	146.75
10	79.04	79.16	20	154.02	154.12

* Values from (6-9) band.

† Average from $\lambda\lambda 4709.3$ and 4236.5 .

TABLE III.—(Continued).

 $\Delta_2 T'''(K)$ VALUES $v'' = 3$

K	(0-3) 5228.3	(1-3) 4651.9	(2-3) 4199.2	K	(0-3) 5228.3	(1-3) 4651.9	(2-3) 4199.2
1	11.21	11.39	11.12	20	152.49	152.53	152.47
2	18.59	18.19	18.49		—	152.50	—
3	26.16	26.60	26.03	21	159.90	160.11	159.65
4	33.32	33.61	33.44		159.79	159.90	—
5	40.97	40.99	40.87	22	167.18	167.30	167.27
6	48.32	48.49	48.41		167.32	167.37	—
7	55.82	55.97	55.86	23	174.67	174.73	174.66
8	63.30	63.28	63.33		174.82	175.03	—
9	70.80	70.38	70.74	24	181.99	182.07	—
10	78.35	78.37	78.28		182.18	182.29	—
	—	—	—	25	189.37	189.49	—
11	85.87	85.78	85.58		189.44	189.61	—
	—	85.77	—	26	—	197.71	—
12	93.26	93.22	93.20		—	197.67	—
	—	93.26	—	27	—	204.18	—
13	100.88	100.71	100.52		—	204.40	—
	—	100.80	—	28	—	210.62	—
14	108.14	107.85	108.00		—	210.51	—
	—	107.87	—	29	—	218.81	—
15	115.52	115.53	115.41		—	219.00	—
	—	115.46	—	30	—	225.84	—
16	123.03	122.88	122.80		—	226.21	—
	—	122.98	—	31	—	233.38	—
17	130.62	130.33	130.26		—	233.12	—
	—	130.05	—	32	—	240.79	—
18	137.83	137.82	137.68		—	240.56	—
	—	137.84	—	33	—	248.29	—
19	145.17	145.11	145.10		—	248.11	—
	—	145.07	—				

TABLE III.—(Continued).

 $\Delta_2 T''(K)$ VALUES $v'' = 4$

	(1-4)	(2-4)	(3-4)		(1-4)	(2-4)	(3-4)
<i>K</i>	5148.8	4599.9	4166.8 4166.4	<i>K</i>	5148.8	4599.9	4166.8 4166.4
1	11.05	11.01	11.03	16	121.53	121.48	121.26
2	—	18.46	18.51		121.61	—	121.54
	—	—	18.50	17	128.91	129.16	128.95
3	25.94	25.54	25.90		128.99	—	128.86
	—	—	25.83	18	136.50	136.06	136.22
4	32.99	33.22	33.26		136.20	—	136.28
	—	—	33.18	19	—	143.34	143.41
5	40.55	40.64	40.57		—	—	143.31
	—	—	40.62	20	—	150.81	151.01
					—	—	—
6	48.05	48.16	48.02	21	—	158.26	158.20
	—	—	48.14		—	—	158.19
7	55.30	55.30	55.25	22	—	165.52	165.42
	—	—	55.31		—	—	165.55
8	62.67	63.04	62.70	23	—	172.83	172.86
	—	—	62.62		—	—	172.75
9	70.07	69.98	70.08	24	—	180.08	—
	—	—	70.02		—	—	—
	—	—	70.20	25	—	187.39	187.43
10	77.48	77.27	77.37		—	—	187.41
	—	—	77.22				
				26	—	194.67	—
11	85.07	84.97	85.23		—	—	—
	84.88	—	84.76	27	—	202.09	201.93
12	92.25	91.93	92.06		—	—	201.98
	92.22	—	92.13	28	—	209.20	—
13	99.56	99.26	99.46	29	—	215.72	—
	99.79	—	99.40	30	—	223.46	—
14	106.89	106.76	106.99				
	106.81	—	106.77	31	—	231.34	—
15	114.09	114.17	114.24	32	—	239.04	—
	114.03	—	114.14	33	—	246.28	—

TABLE III.—(Continued).

 $\Delta_2 T''(K)$ VALUES $v'' = 5$

		(2-5)	(3-5)		
		5076.5	4554.4 4553.2		
K				K	
1	(10.90)	—	—	13	98.34
	—	—	11.15		98.48
2	18.32	—	18.36	14	105.72
	—	—	18.30		105.77
3	25.75	—	25.48	15	112.82
	—	—	25.43		113.13
4	32.99	—	32.54		113.05
	—	—	32.69	16	119.81
5	40.26	—	40.28		120.20
	—	—	40.23	17	127.33
					127.49
6	47.55	—	47.80	18	134.75
	—	—	47.66		134.77
7	54.69	—	54.79		134.66
	—	—	54.72	19	142.30
8	61.91	—	62.19		142.25
	—	—	62.10		142.02
9	69.27	—	69.53	20	(149.42)
	—	—	69.27		149.32
10	76.48	—	76.53		149.33
	—	—	76.44	21	156.46
					156.59
11	83.10	—	83.94	22	163.98
	—	—	83.90		164.02
12	90.95	—	91.08		163.99
	—	—	91.49	23	—
					170.97
					171.05
				24	—
					178.23
					178.33

() Calculated from interpolated R lines.

TABLE III.—(Continued).

 $\Delta_2 T''(K)$ VALUES $v'' = 7$

K	Parker†	(5-7) $\lambda 4486$	K	Parker†	(5-7) $\lambda 4486$
1	10.79	—	13	96.14	96.23
2	17.97	—		—	96.18
3	25.08	24.70	14	103.39	103.59
	—	24.83		—	103.42
4	32.48	31.92	15	110.66	110.54
	—	32.00		—	110.72
	—	31.99			
5	39.43	39.29	16	117.68	117.65
	—	39.01		—	118.06
			17	124.75	124.65
6 •	46.43	46.29		—	124.87
	—	46.12	18	131.57	131.83
7	53.62	53.31		—	131.69
	—	53.58	19	138.90	138.94
8	—	60.79		—	138.77
	—	60.73	20	146.09	—
9	67.83	67.74		—	—
	—	67.76			
10	—	74.99	21	153.02	152.59
	—	74.94		—	152.77
			22	—	—
11	82.00	82.01		—	—
	—	81.95	23	—	166.93
12	89.11	89.10		—	167.11
	—	89.17			

 $v'' = 8$

K	Average*	(6-8) $\lambda 4466.6$	K	Average*	(6-8) $\lambda 4466.6$
1	10.80	10.61	6	45.99	45.93
2	17.89	17.68	7	52.88	52.93
3	24.57	24.64	8	60.19	59.97
4	30.89	31.85	9	67.01	67.05
5	38.81	39.21	10	74.13	74.00

† From (4-7) band.

* Average of results of Coster and Brons (10-8) and Parker (5-8).

TABLE III.—(Continued).

 $\Delta_2 T''(K)$ VALUES $v'' = 8$ —(Continued).

K	Average*	(6-8) $\lambda 4466.6$	K	Average*	(6-8) $\lambda 4466.6$
11	81.34	80.93	16	116.29	116.27
12	88.35	88.01	17	—	123.05
13	95.14	95.19	18	—	130.46
14	102.22	102.35	19	—	137.51
15	109.27	109.79	20	—	144.11

TABLE IV.

THEORETICAL AND OBSERVED ORIGINS.

Band	Observed	Calculated†
(2-2)	25939.8	25939.8
(3-4)	24013.9	24014.5
(3-5)	21971.1	21971.6
(5-7)	22305.4	22305.0
(6-8)	22406.5	22404.0
(0-3)	19139.7	19139.8
(1-4)	19434.7	19434.6
(2-5)	19710.4	19711.6

* Average of results of Coster and Brons (10-8) and Parker (5-8).

† These are calculated from the expression $\nu = 25566.0 + 2396.22\nu' - 24.070\nu'^2 - 0.6365\nu'^3 - .04949\nu'^4 - (2191.02\nu'' - 16.196\nu''^2 - 0.0400\nu''^3)$ given by Coster and Brons.

TABLE V.
VALUES OF B_v' AND B_v''

v	B_v' (Parker)*	B_v'' (C & B)*	B_v' (C & T)	B_v'' (C & T)
0	2.074		2.073	
1	2.052		2.051	
2	2.028	1.880	2.026	1.879
3	1.998	1.860	2.004	1.863
4		1.840		1.843
5	1.932	1.820	1.926	1.826
6	1.895		1.897	
7		1.780		1.780
8		1.760		1.768

* Values of B_v' and B_v'' as calculated from expressions given by Parker and Coster and Brons respectively compared with values measured by us.

TABLE VI.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
	Smoothed Values	Observed $R_1(K)$	$R_2(K)$	K'		Smoothed Values	Observed $P_1(K)$	$P_2(K)$	(III-II) $P_3(K)$	(VIII -VII)	(IV-II)	(IX- VII)
Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81	Origin 21970.81
R(0)	74.88	21974.49	—	0 P(1)	67.10	21966.60	—	—	—	.50	—	—
R(1)	79.26	78.74	21979.26	1 P(2)	63.77	63.34	63.77	63.77	—	.39	—	.43
R(2)	83.97	83.14	83.82	2 P(3)	60.90	60.44	60.90	60.90	—	.52	—	.46
R(3)	89.11	88.17	89.11	3 P(4)	58.42	57.66	58.42	58.39	—	.83	—	.76
R(4)	21994.60	93.30	94.50	4 P(5)	56.39	55.26	56.39	56.42	—	.94	—	.13
R(5)	22000.54	98.62	22000.06	5 P(6)	54.53	53.02	54.53	54.27	—	1.30	—	1.51
R(6)	06.74	22003.97	07.74	6 P(7)	53.06	50.82	53.06	52.40	—	1.92	—	2.24
R(7)	13.33	09.18	13.51	7 P(8)	52.05	49.18	52.05	53.02	—	2.77	—	2.87
R(8)	20.09	13.51	20.09	8 P(9)	51.30	46.99	51.30	51.41	—	4.15	—	4.31
R(9)	27.26	35.36		9 P(10)	50.85	43.98	50.85	50.82	—	6.58	—	6.87
R(10)	34.72	40.36		10 P(11)	50.82	58.83	50.82	50.82	—	8.10	—	8.01
R(11)	42.90	46.71		11 P(12)	50.82	56.42	50.82	56.42	—	5.64	—	5.60
R(12)	50.87	54.11		12 P(13)	51.41	55.63	51.41	55.63	—	3.81	—	4.22
R(13)	59.42	62.19		13 P(14)	52.40	55.63	52.40	55.63	—	3.24	—	3.23
R(14)	68.31	70.79		14 P(15)	53.61	56.42	53.61	56.42	—	2.77	—	2.81
R(15)	77.50	79.55		15 P(16)	55.26	57.66	55.26	57.66	—	2.48	—	2.40
R(16)	87.06	88.96		16 P(17)	57.27	59.35	57.27	59.35	—	2.05	—	2.08
R(17)	96.94	98.73		17 P(18)	59.57	61.47	59.57	61.47	—	1.90	—	1.90
R(18)	22107.25	22108.85		18 P(19)	62.28	63.96	62.28	63.96	—	1.79	—	1.78
R(19)	17.84	19.42		19 P(20)	65.23	66.60†	65.23	66.60†	—	1.60	—	1.37
R(16)				20 P(21)	68.51	70.10	68.51	70.10	—	1.58	—	1.59

† Superposed by another line.

TABLE VII.

	I	II	III	IV	V
	Smoothed $\Delta_2 T(K)$ values	$(\Delta_2 T_1 \text{ obs.} - \Delta_2 T_{\text{smoothed}})$ (3-5)	$(\Delta_2 T_1 \text{ obs.} - \Delta_2 T_{\text{smoothed}})$ (3-4)	$(\Delta_2 T_2 \text{ obs.} - \Delta_2 T_{\text{smoothed}})$ (3-5)	$(\Delta_2 T_2 \text{ obs.} - \Delta_2 T_{\text{smoothed}})$ (3-4)
1	12.03	+0.11	+0.23	—	—
2	20.04	-0.24	-0.11	+0.01	-0.02
3	28.06	-0.33	-0.25	+0.15	+0.12
4	36.06	-0.42	-0.48	+0.02	-0.05
5	44.04	-0.68	-0.72	-0.40	-0.27
6	52.02	-1.07	-1.21	+1.45	+1.41
7	60.00	-1.64	-1.98	+1.11	+1.07
8	67.97	-3.64	-3.84	-0.92	-0.79
9	75.94	+12.43	+12.33	-0.11	-0.12
10	83.91	+12.47	+12.43	+0.01	-0.01
11	91.88	-4.00	-3.99	0.0	0.0
12	99.94	-2.25	-2.36		
13	107.93	-1.37	-1.44		
14	115.87	-0.71	-0.87		
15	123.86	-0.73	-0.72		
16	131.76	-0.46	-0.42		
17	139.70	-0.32	-0.39		
18	147.69	-0.31	-0.29		
19	155.56	-0.10	-0.16		

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THE RELATION OF THE EYES TO CHROMATOPHORAL
ACTIVITIES.

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WITH ONE PLATE.

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1. INTRODUCTION.

IN the course of three independent investigations on the color changes in animals we were impressed with the remarkable uniformity of response to loss of the eyes as shown by the several animals under consideration. When it is recalled how diverse the details of chromatophoral control have proved to be, not only between representatives of different groups of animals but between even closely related species, the great uniformity of the response to the loss of the eyes is truly surprising. The animals upon which we worked were the common frog, *Rana pipiens* Schreber, the shrimp, *Palaemonetes vulgaris* (Say), and two fishes, *Fundulus heteroclitus* (Linn.) and *Ameiurus nebulosus* (Lesueur). The details of the chromatophoral responses of these animals to the loss of the eyes will be discussed on the following pages.

The importance of the eyes in this type of reaction appears to have been pointed out first by Lister (1859, p. 638), who, in describing the results of his experiments on enucleated frogs, remarked that what he had seen "indicated pretty clearly that the eyes are the only channels through which the rays of light gain access to the nervous system so as to induce changes of colour in the skin." This conclusion was subsequently arrived at independently by Pouchet, who in a most important series of papers published between 1871 and 1880 demonstrated the necessity of the eyes in the color responses of fishes and crustaceans and further showed in the fishes, at least, that the whole reaction was dependent upon the sympathetic, or better the autonomic, nervous system. So complete and so full were Pouchet's proofs of the nervous control of chromatophores that for many years after his time no one suspected any other means to this end.

In 1898 Corona and Moroni showed that adrenalin when introduced into the blood of a frog had a profound effect upon its color cells. This unique observation was subsequently confirmed by Lieben (1906), who made a still further investigation of the subject. Comments by Fuchs (1914) on these two pieces of work led Redfield (1918) to study

the effects of adrenalin on the chromatophores of the lizard, *Phrynosoma*, with the result that this hormone was found to be a potent agent in inducing chromatophoral change.

Other such substances were likewise soon shown to be of great importance in color responses. Through the work of Adler (1914), Smith (1916), and Allen (1917) the technique of hypophysectomy on larval amphibians was developed, and it was pointed out that hypophysectomized individuals were always very light colored. The significance of this change from the standpoint of internal secretions and the chromatophore system was first indicated by Atwell in 1919. Two years later Swingle (1921) observed that tadpoles became dark when a part of the pituitary gland was transplanted into them. Hogben and his associates were thereby led to an extensive and thorough investigation of the pituitary gland and its secretions in relation to chromatophoral changes with results that were truly revolutionary. These, when coupled with the generally negative outcome of experimental nerve-cutting, led Hogben (1924, p. 92) to conclude that the color changes in amphibians involve little or no direct innervation and depend upon fluctuating amounts of pituitary secretion. In later studies that were carried on by Hogben and Slome (1931) on the South African clawed toad, *Xenopus*, a dual endocrinal control of amphibian color change was suggested, the pituitary and some second unknown factor, but even in this instance the added element was still regarded as humoral in character. Thus in amphibians, at least, the nervous interpretation of chromatophoral control was in large part abandoned for one based upon special hormones, or what are now called neurohumors.

At about the same time that the amphibian chromatophores were being shown to be under the control of neurohumors the same was being done for the color cells of crustaceans. In 1925 Koller made an interesting observation on the shrimp *Crangon* in that he noticed that an individual of ordinary coloration after having eaten another shrimp yellow in tint assumed a yellow color. This change suggested to him the possibility that the blood of the originally yellow individual contained a substance which on being transferred to that of the other shrimp induced it to become yellow. He was, therefore, led to experiment with the transfusion of blood and made the important discovery that when the blood from a dark shrimp was injected into the body of a light one the latter quickly became dark, though blood from a light shrimp had no effect whatever on the color conditions of another light one. He was, therefore, led to believe that the color changes in

crustaceans were influenced, and perhaps controlled, by internal secretions and that consequently any final study of these changes called for a new type of attack with an appropriate technique. In 1928 Perkins made the important discovery that the eye-stalks of *Palaemonetes* contained a substance which when extracted in seawater and injected into the blood of a dark individual would induce it to turn light. This discovery was further demonstrated in Crangon by Koller (1928), who declared that in this shrimp an organ for the production of an expanding hormone was to be found in the rostral region of the animal. These important results were confirmed with slight variations in detail by several subsequent workers, who were, further, unable to find any evidence whatever for the older view that the chromatophores of crustaceans were under the direct control of nerves. Thus the belief steadily gained ground that the crustacean chromatophoral system is organized on a purely neurohumoral basis.

Notwithstanding the validity of this conclusion and the recent extensive growth of evidence in favor of it as applied, for instance, to such animals as crustaceans and amphibians, it still remains true that in many fishes and lizards a nervous control of chromatophores can be most easily demonstrated. It is, therefore, held by a number of recent workers that chromatophores as a whole are subject to two sets of influences, nervous and humoral, and that in certain instances one set predominates and in others, the other one. A new approach on this problem, which seems to have been in the mind of Giersberg (1930), has been rather fully developed by one of us (Parker, 1932) under the name of neurohumoralism. According to this view, the first step in the color changes of actively chromatic animals is stimulation of the eye, from which nervous impulses pass either to glands of internal secretion whose products, the neurohumors, are then carried in the blood to the appropriate chromatophores or over nerves to these effectors which are excited by secretions, also neurohumors, from the terminals of these nerves, and not by what might be called direct nervous action. Thus all chromatophoral systems are in each instance partly nervous and partly humoral and differ chiefly in the extent to which each of the two elements enters into their organization.

The eyes and their relations to chromatophoral responses will be taken up in the present paper from this most recent standpoint. An attempt will be made to show the broad relations of the eyes to color changes, and this will be undertaken not simply from what we have found on the four animals named but also from what earlier workers have contributed. Three summaries of earlier investigations are

given in tabular form, one each for amphibians, for crustaceans, and for fishes. The tables are, of necessity, not complete though they represent a reasonably full survey of past work. Their omissions are chiefly due to our inability to decide with certainty what was the real meaning of some of the earlier workers. This is especially true of the column for "darkness," where it was often impossible to decide whether in a given reference it was intended to state that the eyeless animal had been exposed to complete absence of light or to a condition of only relative darkness. An attempt has been made to keep fairly close in the tabulation to the descriptive expressions of the various investigators, but here too the necessity for abbreviation may have led us to represent the original observation imperfectly. The term "dark" in the table stands for a similar expression in the original records and is regarded as essentially equivalent to the descriptive term "expanded" as applied to chromatophores. Notwithstanding the limitations necessitated by the tables, it is believed that they represent a general survey of the subject such as could be obtained in no other way.

2. IN AMPHIBIANS.

The common spotted frog, *Rana pipiens*, shows, like other members of its genus, a well marked range of color changes. These changes affect, of course, the lighter parts of its skin not so much its permanent, large, dark spots. In an illuminated glass-vessel with white walls and water about a centimeter deep a normal spotted frog in a few hours acquires a relatively light tint and, with very slight fluctuations, re-

EXPLANATION OF FIGURES.

All figures are from *Rana pipiens*. We are indebted to Dr. F. M. Carpenter for the photographs.

FIGURES 1, 2, and 3 are from the same frog in different states.

FIGURE 1. Normal frog in the light state.

FIGURE 2. Eyeless frog showing the partly dark state.

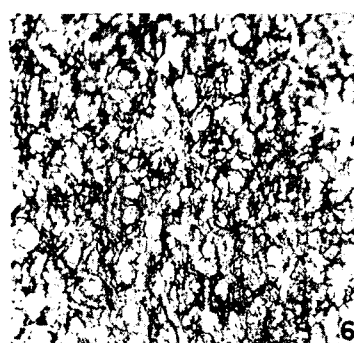
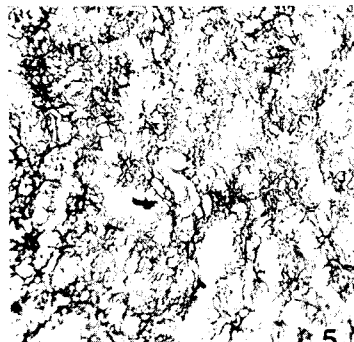
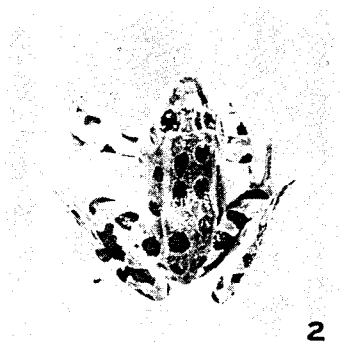
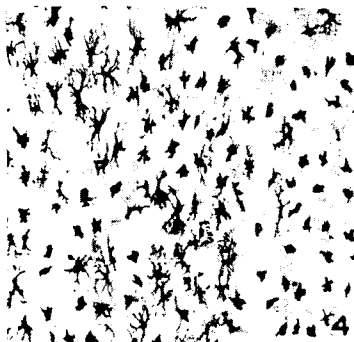
FIGURE 3. Normal frog in the dark state.

FIGURES 4, 5 and 6 are microscopic views of the melanophores in the web of a frog's hind foot.

FIGURE 4. Melanophores with fully concentrated pigment from a normal light frog. (Figure 1).

FIGURE 5. Melanophores with partly dispersed pigment from an eyeless frog. (Figure 2.)

FIGURE 6. Melanophores with fully dispersed pigment from a normal dark frog. (Figure 3.)



mains persistently of this tone (Fig. 1). In a similar vessel but with black walls, the normal animal assumes a deep brownish tint (Fig. 3) and maintains this with little change indefinitely. The tests from which these records were taken, ran over nearly two weeks. They were carried out in a laboratory provided with artificial electric light that was operated day and night. The temperature was approximately 20° C.

Frogs that had been tested in this way were eventually enucleated, and in carrying out this operation it was found convenient first to stupefy the animals by keeping them for about a quarter of an hour in a mixture of ice and water. Under these circumstances they soon become very torpid and the operation of enucleation can be easily and satisfactorily performed. The frogs recover from the cold rapidly and, as no drug has been used, they quickly return to a normally active state. Within a few days after the operation their eyelids heal and such a frog, if fed from time to time, will live for many months.

After enucleation the animals, having been dark from the cold water, passed at once into a moderately dark phase without showing the initial light stage recorded by several workers (Lister, 1859; Kropp, 1927). The omission of this initial light condition is to be attributed to our method of stupefaction. The final tint of the animals (Fig. 2) was darker than that midway between the extremes of light (Fig. 1) and of dark (Fig. 3) but never reached the maximum depth of color. The transparent web of the foot in the enucleated individual showed a rich branching of the melanophores (Fig. 5), but not by any means so rich as that seen at maximum darkness (Fig. 6). It was very much more pronounced than the slight branching seen in light individuals (Fig. 4).

Enucleated frogs were tested in pairs to ascertain whether they showed color changes to any degree. Six pairs, the members of each pair having been closely matched in tint, were put in six white-walled glass-vessels illuminated by electric lights from above and provided with a shallow layer of water. They were compared from time to time during the day and for a period of over a week. One mate of one pair died before the expiration of the test but the other five pairs survived with satisfactory results. Though each pair was started with both members of the same tint, in a day or so the two showed observable differences. These differences appeared to be slight fluctuations, one side or the other, of the dark tint already described as somewhat less dark than the maximum. At no time did these animals show the extreme lightness or darkness possible to normal frogs. The extreme

fluctuations of the enucleated individuals fell far short of those of normal ones.

A similar set of tests was run with enucleated frogs kept for a number of days in dark-walled illuminated vessels and with essentially similar results to those just recorded. As an outcome of these tests it was quite clear to us that an enucleated frog could spontaneously change its color in either a light or a dark direction, though to only a very limited extent. In this respect we can confirm the observations of Kropp (1927), but we have seen nothing to corroborate the view of Carnot (1896) that blinded frogs respond in course of time more or less fully to environmental changes. So far as we could judge, an enucleated frog was just as likely to turn slightly dark as it was to turn slightly light in an illuminated white vessel or in a black one. For this reason, we are not inclined to think that the photic sensitivity of the skin of this animal (Parker, 1903) has any influence on its chromatophoral changes.

Our observations on the frog agree fairly well with those of earlier workers on this animal, on tadpoles, on *Xenopus*, and on *Diemyctilus* as given in Table 1. In most of these records the animals are said to darken finally after the loss of the eyes and to be more or less fluctuating in tint. We have seen nothing to support Biedermann's contention (1892) that the eyeless frog is essentially the same in its color changes as is the normal individual. In our tests eyeless individuals always fell far short of the usual chromatophoral range of normal animals.

Eyeless frogs when placed in complete darkness exhibited no special change of tint. They were of an intermediate dark tone and maintained this condition, as has been reported by other investigators (see Table 1).

That eyeless frogs do not lose their capacity for color change in consequence of the loss of their eyes can easily be shown by the injections of appropriate hormones. If into the lymph spaces on the back of a frog that has been eyeless for some weeks, 0.2 cc. of adrenalin (Parke, Davis & Co.) is injected the animal becomes light tinted in from ten to fifteen minutes. The tint attained is in all respects like that seen in a normal frog after a corresponding injection. On injecting pituitary extract (Parke, Davis & Co., obstetrical preparation) into an eyeless frog it becomes dark to a maximum degree, which is a much deeper tint than that ever attained by such individuals under ordinary circumstances. Hence, we conclude that the eyeless condition has in no way disturbed the power of chromatophoral changes in the frog.

TABLE 1.

AMPHIBIANS.

States of the melanophores in various eyeless amphibians in light and in darkness, as recorded by various investigators. The forms are referred to under their common names or their generic names, and the references are arranged for the most part historically with dates agreeing with those in the bibliographies.

Investigator	Date	Amphibian	Eyeless	
			In Light	In Darkness
Lister	1859	Frog	Light then dingy	Darkish
Dutartre	1890	Frog	Changeable	
Biedermann	1892	Frog	Same as normal	
Carnot	1896	Frog	Follows environment	
Rogers	1906	Diemyletilus	Dark	Dark
Babák	1910	Frog tadpole	Very dark	Light
Babák	1910	Amblystoma larva	Dark	
Babák	1913	Amblystoma larva	Dark	
Laurens	1914	Amblystoma larva	Dark	
Laurens	1915	Amblystoma larva	Dark	
Laurens	1917	Amblystoma larva	Dark	
Hooker	1914	Frog tadpole		
Hogben, Winton	1923	Frog		Contracted then expanded Mostly dark
Hogben	1924	Frog	Dark	
Kropp	1927	Frog	Light, then follows environment	
Kropp	1927	Frog tadpole	Dark	Intermediate
Slome, Hogben	1928	Xenopus	Dark	
Hogben, Slome	1931	Xenopus	Dark	

The only eyeless amphibian whose chromatophoral responses fail to agree in general with those already discussed is the larval Amblystoma. This animal has been studied by both Babák (1910) and Laurens (1915, 1917). The eyeless larvae of this form are stated by both these workers to become dark in ordinary illumination. In this respect they agree with other amphibians, as Table 1 shows, but instead of remaining dark when placed in darkness, as most amphibians do, they become light. This response to darkness is very striking and has a bearing on the question we are discussing, because it shows that beside the eye some other factor is concerned with chromatophoral control in the young Amblystoma. Such, indeed, may be true

to some degree of other amphibians (see Frog tadpole according to Hooker, 1914, and *Xenopus* according to Slome and Hogben, 1928, in Table 1). But however this may be, the supremacy of the eye in the group as a whole cannot be denied. All blinded amphibians in ordinary daylight assume a fairly dark to a full dark tone and exhibit under these conditions only minor fluctuations. The older workers have at times discussed this situation on the assumption of an interference with a direct nervous control, but in our opinion it results from an interruption in the secretory mechanism that has to do with the formation of the necessary neurohumors, for, notwithstanding the recent contention of Karásek (1933) that nerves play a direct part in the chromatophoral system of amphibians, we regard this control as secretory and only secondarily concerned with nerves.

3. IN CRUSTACEANS.

The all-importance of the eyes in the control of the chromatophores of crustaceans was first demonstrated in *Palaemon* by Pouchet in 1872. Pouchet's studies on the color changes of fishes had shown him that the autonomic nerves were the means of communication between the eyes and the chromatophores and he was, therefore, led to believe that impulses originating in the eyes of shrimps must reach and control the distant chromatophores also by means of nerves. This opinion he held notwithstanding the fact that all his experiments on the cutting of nerves in crustaceans yielded only negative results (1872 to 1876). The majority of investigators of the chromatophoral system in crustaceans who followed Pouchet, accepted his view though they too failed to find any supporting evidence from the standpoint of nerve cutting (Mayer, 1879; Matzdorff, 1883; Fröhlich, 1910; Menke, 1911; Degner, 1912). It was not till 1925, as already stated, that Koller began to suspect a humoral control of crustacean chromatophores. In 1928 Perkins subjected *Palaemonetes* to an exhaustive series of tests in nerve cutting and with entirely negative results. In consequence both he and Koller finally were led to declare against a nervous interpretation of these activities and in favor of a purely humoral one. Our view coincides with theirs. So far as the crustaceans are concerned, their chromatophoral system appears to be entirely free from direct nerve intervention and is organized on a neurohumoral basis.

Palaemonetes vulgaris, the shrimp studied by us, possesses the usual type of crustacean chromatophore, namely, one composed of a number of conjoined cells containing several pigments. The pigments

in *Palaemonetes vulgaris* are of four kinds: red, yellow, blue, and white. In action these four can be shown to be fully independent one of the other and hence require four independent exciting mechanisms. By means of these color-changes, singly or in combination, *Palaemonetes* may adapt itself well to backgrounds of white, yellow, red, blue, green, dark gray, or black. These responses involve not only a migration of pigment but also a production and a destruction of this material.

A neurohumor producing a concentration of the white pigment in *Palaemonetes* occurs in its eye-stalks and in some tissue in the anterior region of the cephalothorax. Neurohumors for the concentration of the red and the yellow pigments come from certain central nervous organs. The source of the neurohumor for the concentration of the blue pigment has not been discovered. *Palaemonetes*, unlike Crangon (Koller, 1928), appears to produce no neurohumors for the dispersion of its pigments. This process is believed to follow from the absence of the appropriate concentrating neurohumor and to be a property of the chromatophore itself.

In Crangon where, according to Koller, there is a dispersing as well as a concentrating neurohumor the condition is more nearly parallel with that in the frog, in which, in addition to a pronounced dispersing neurohumor, there is reason to believe that a concentrating one may occur (Slome and Hogben, 1928).

Palaemonetes, with its four sets of mutually independent pigments, presents a much more complex picture than that of the frog, with only melanophores. This complexity is to be seen in the responses following the removal of the eyes. As would be expected, the loss of one eyestalk shows little or no effect on the color changes, but when both are removed the shrimp assumes a dark reddish brown tone, which is ordinarily persistent. This state is brought on by a gradual and finally complete dispersion of the yellow and red pigments and by a formation of blue. The white pigment shows no special response. The resultant dark coloration was found to maintain itself with no apparent change when the animal was kept in an illuminated black-walled vessel, a similar white-walled vessel, or in complete darkness.

The dark condition of the eyeless *Palaemonetes* is in agreement with what has been recorded for most other crustaceans under like circumstances (see Table 2). The exceptions to this statement, as can be seen by inspecting the table, are *Idotea*, whose chromatophoral system is apparently not very active, and the very remarkable species *Hippolyte varians* studied by Keeble and Gamble (1900, 1904) and by

TABLE 2.

CRUSTACEANS.

States of the chromatophores in various eyeless crustaceans in light and in darkness as recorded by various investigators. The forms are referred to under their generic names, and the references are arranged for the most part historically with dates agreeing with those in the bibliography.

Investigator	Date	Crustacean	Eyeless	
			In Light	In Darkness
Pouchet	1872	Palaemon	Fully dark	
Pouchet	1872	Palaemon	Fully dark	
Pouchet	1874	Palaemon	Red	
Pouchet	1876	Palaemon	Dark red	
Jourdain	1878	Nika	Dark red	Red
Mayer	1879	Idotea	Unchanged	
Keeble and Gamble	1900	Hippolyte	Contracted	Nocturne
and	1900	Palaemon	Expanded	Contracted
Gamble and Keeble	1904	Macromysis	Expanded	Contracted
Przibram	1902	Carcinus	Red	
Bauer	1905	Idotea	Intermediate	Midgray
Fröhlich	1906	Palaemon	Dark brown	Red brown
Fröhlich	1910	Palaemon	Dark brown	Red brown
Meguśar	1908	Gelasimus	Dark	
Meguśar	1912	Palaemonetes	Red brown	
Meguśar	1912	Palaemon	Dark	
Meguśar	1912	Potamobius	Dark	
Minkiewicz	1908	Hippolyte	Contracted	
Dollein	1910	Leander	Brown	Reddish
Tait	1910	Ligia	Fully dark	
Degner	1912	Crangon		Expanded
Bauer and Degner	1913	Leander	Brown red	Expanded
Piéron	1913	Idotea	Expanded	
Piéron	1914	Idotea	Expanded	
Koller	1928	Crangon	Intermediate	
Koller	1930	Crangon	Intermediate	
Perkins	1928	Palaemonetes	Dark	Expanded
Smith	1930	Macrobrachium	Expanded	
Brown	1933	Palaemonetes	Dark	Dark

Minkiewicz (1908). This remarkable shrimp stands out in contrast with other crustaceans in the great variety of its color phases and patterns, its marked daily rhythm which persists some time after the natural light and darkness relations have been interrupted, and in its assumption of a uniform, nocturnal, blue phase in darkness irrespective of its previous diurnal state. With the loss of its eye-stalks it passes over into a permanent “nocturne,” that is, a state in which

its chief chromatophores are contracted. This state is in strong contrast with, for instance, that of *Palaemon* and *Macromysis*, as well as with other species of *Hippolyte*, all studied by Keeble and Gamble and in which the loss of the eye-stalks is followed by darkening. *Hippolyte varians* must, therefore, be set aside as a species whose chromatophoral organization is in a measure unique and in that sense not easily compared with other crustaceans.

Excepting this remarkable form, whose chromatophoral activities are still worthy of further study, all the other crustaceans with active chromatophoral systems and recorded in Table 2, agree in becoming more or less completely dark on the loss of the eye-stalks. This operation, like the corresponding one in the frog, seems to bring to an almost full standstill those processes that modify neurohumoral activity in relation to environmental color adaptation. The operation not only checks these processes but, as has been pointed out by Koller (1930), it removes from the animal what seems to be the most important source of the neurohumors, the eye-stalk itself. Yet, notwithstanding this profound change, most crustaceans respond to the loss of the eye-stalks with a darkening of the body as remarkable as it is uniform.

4. IN FISHES.

If the chromatophoral systems in amphibians and in crustaceans yield very strong evidence of what is usually regarded as an almost strictly humoral system, the fishes exhibit conditions that are equally favorable for nervous control. The turbot was the first form which in the hands of Pouchet (1871) yielded evidence of a most convincing kind that its dermal melanophores were controlled by nerves. When cuts were made across bundles of nerves in this fish, the pigment in the melanophores in the denervated region became dispersed and thus was produced a dark area corresponding to that of denervation. This experiment was tried by Pouchet on a variety of fishes and with results confirmatory of his first observations. It has been repeated by a large number of later workers on many fishes and with great uniformity of outcome.

Nevertheless, Meyer in 1931 pointed out the remarkable fact that if the serum of a flatfish that had been darkened by having been kept one or two weeks in an illuminated dark-walled aquarium was injected into a light-tinted fish, within five minutes a dark spot appeared in the region of injection. This spot continued to increase in intensity for half an hour or so, after which it slowly disappeared. In a similar

way, serum from a light-tinted fish when injected into a dark fish was said to produce a temporary light spot. This is strong evidence in favor of a humoral interpretation of color changes, and from a group of fishes which of all others seemed to be the most favorable for the nervous plan of color control. The clue contained in these observations was followed up by several investigators, and it soon became evident that fishes were by no means uniform in the methods by which their chromatophores were controlled. In certain instances they exhibited good examples of what had been regarded as direct nerve effects and in others conditions were found where humoral agents seemed to play at least some part. Thus in *Mustelus*, the dark phase of this fish was shown to be called forth by a pituitary neurohumor (Lundstrom and Bard, 1932) whereas the light phase was due to direct nerve action (Parker and Porter, 1934). In *Ameiurus* the dark state was due in part to direct nerve action and in part to a pituitary hormone and the light phase to direct nerve action only (Parker, 1934). In *Fundulus*, Matthews (1933) showed that the serum from an individual of one extreme tint has no effect upon another of the opposite tint, and yet Parker (1934) has given good reason for the opinion that the color changes in this fish are induced by neurohumors that come directly from the nerves. With this diversity of control in mind, our own observations on the relations of the eyes to color changes in *Fundulus* and in *Ameiurus* will now be considered.

Normal *Fundulus heteroclitus* has a well defined dark phase as well as a light one corresponding to the dark or the light character of its environment. When both eyes are removed *Fundulus* changes irrespective of its previous state to a dark tint that is not quite so dark as the maximum shade of this fish. This tint is maintained unchanged in illuminated vessels with black walls as well as in those with white walls. Our results confirm those of Wyman (1924) and of Sumner (1933) but not those of Parker and Lanchner (1922), according to whom blinded fishes were found to be light. This difference is to be attributed to a difference in the technique used by Parker and Lanchner, as contrasted with other workers. Whereas most workers blinded their fishes by cutting the optic nerves or by enucleation, Parker and Lanchner attempted this by covering the fish's eyes with an impervious paste. This technique was, without doubt, inadequate and in consequence of the accidental leakage of light into the eyes rendered the fish light.

Eyeless *Fundulus* maintain their dark tint under all circumstances

excepting when they are in darkness. If a number of *Fundulus* whose optic nerves have been cut are transferred to a dark room they soon become slightly but noticeably light. This new condition is retained as long as they are kept in the dark but is lost by a return of the fishes into the light. This rather remarkable condition resembles that recorded for *Amblystoma* larvae by Babák (1910) and by Laurens (1914, 1915) where blinded individuals, though dark in the light, become light tinted in darkness. None of these changes in *Fundulus* are concerned with any obvious production or destruction of melanin such as is known to occur in this fish (Odiorne, 1933) and in *Lebistes* (Sumner and Wells, 1933) in the course of time. They belong to what are ordinarily called physiological, rather than morphological, changes.

Ameiurus, like *Fundulus*, exhibits two well marked extremes of color, dead black on the one hand and a light greenish yellow on the other. It changes in response to environmental differences as does *Fundulus*, but the rate of change is much slower in *Ameiurus* than in *Fundulus*. When catfishes are enucleated they assume a very dark tint, though not the maximum shade, and they retain this condition in any illuminated aquarium irrespective of background (Van Heusen, 1917; Bray, 1918; Pearson, 1930). Like *Fundulus*, they become slightly lighter when they are put in complete darkness and gain in depth of color when they are returned to the light. *Ameiurus*, like *Fundulus*, can increase or decrease to no inconsiderable amount its store of melanin, but the changes thus far described for this fish are due primarily to the shifting of melanin within its chromatophores and not to a change in the amount of this pigment.

Both *Fundulus* and *Ameiurus* respond to the loss of eyes by assuming a relatively constant and moderately dark tint. In this respect they agree with the great majority of fishes whose conditions are given in Table 3.

An inspection of Table 3 will show that very few fishes are exceptions to the rule that enucleation is followed by an early darkening of the skin. Pouchet (1877, 1878, 1880) discovered the remarkable fact that in the trout the removal of one eye, which in most fishes has no observable effect on the color changes of the animal, resulted in a contralateral darkening in this form, a condition in part associated with the optic chiasma. Pouchet's discovery was confirmed by von Frisch (1911), who attributed to abnormal conditions the inability of Steinach (1891) to find similar results. The slowness to respond on the part of certain flatfishes is probably accountable for some records in which these forms were not reported as darkened by blinding

TABLE 3.

FISHES.

States of the melanophores in various eyeless fishes in light and in darkness as recorded by various investigators. The forms are referred to either under their common names or their generic names and the references are arranged for the most part historically with dates agreeing with those in the bibliography.

Investigator	Date	Fish	Eyeless	
			In Light	In Darkness
Pouchet	1871	Turbot	Reddish	
Pouchet	1872	Turbot	Reddish	
Pouchet	1874	Sole	Dark	
Pouchet	1874	Carassius	Dark	
Pouchet	1874	Aspius	Dark	
Pouchet	1874	Gobio	Dark	
Pouchet	1876	Turbot	Red	
Pouchet	1877	Trout	Contralateral dark	
Pouchet	1880	Trout	Contralateral dark	
Lode	1890	Trout	Dark	
Steinach	1891	Pleuronectes	No darkening	
Steinach	1891	Trout	Variable	
Mayerhofer	1909	Esox	Deep green	Lightens
Šecerov	1909	Nemachilus	Dark	
Franz	1910	Pleuronectes	Very dark	
Bauer	1910	Flatfish	Intermediate	Intermediate
Buytendijk	1911	Turbot	Dark or Light	
Sumner	1911	Rhomboidichthys	Dark	
Sumner	1911	Lophopsetta	Dark	
von Frisch	1911	Phoxinus	Dark	Lightens
von Frisch	1911	Carassius	Dark	
von Frisch	1911	Salmo	Contralateral dark	Dark
von Frisch	1911	Perca	Dark	
Polimanti	1912	Rhombus	Variable	
Van Heusen	1917	Ameiurus	Dark	
Bray	1918	Ameiurus	Dark	
Murisier	1920	Salmo	Dark	
Parker & Lanchner	1922	Fundulus	Light	Light
Wyman	1924	Fundulus	Dark	
Tozawa	1924	Goldfish	Dark	
Abolin	1925	Phoxinus	Moderate expansion	
Pearson	1930	Ameiurus	Dark	
Sumner	1933	Fundulus	Dark	
Parker and Porter	1934	Mustelus	Dark	

(Steinach, 1891; Bauer, 1910; Buytendijk, 1911; Polimanti, 1912). What appears to be a real exception among fishes to the rule that enucleation is followed by darkening is seen in Phoxinus. On the

loss of its eye this fish is stated by von Frisch (1911) to be first dark and then variable. Abolin (1925) declared that after the loss of its eyes *Phoxinus* exhibited moderately expanded chromatophores. When it is recalled that after blinding the chromatophores of this fish will still respond with more or less appropriateness to environmental changes of color, its exceptional position must be evident. Its powers of chromatophoral response under such conditions has led to tests with the view of locating some photoreceptors other than the eyes to explain this state, a search that has pointed to the pineal organ, rather than the skin (von Frisch, 1911; Scharrer, 1928), as the part concerned. Thus *Phoxinus* is peculiar in several respects and from this standpoint is perhaps best set off against other fishes, the loss of whose eyes seems always to be associated with a moderate or full darkening of the skin. As with amphibians and crustaceans, the loss of the eyes in most fishes brings to a standstill the mechanism of chromatophoral change and the whole system rests in a state of partial or complete dispersion of pigment.

5. DISCUSSION.

A survey of the chromatophoral responses of the four animals upon which we worked is shown in Table 4. Here it will be seen that so long as the eyes were intact these animals responded to a white or a black illuminated background by appropriate changes and with great uniformity. In the white-walled vessel all were light-colored; in the black-walled one all were dark. In total darkness the uniformity of these animals disappeared. After the loss of the eyes the distinction in response to illuminated white or black surroundings was entirely

TABLE 4.
CHROMATOPHORAL RESPONSES OF FOUR ANIMALS.

Rana, *Palaemonetes*, *Fundulus*, and *Ameiurus*, with or without eyes, kept (1) in an illuminated black-walled vessel, (2) in an illuminated white-walled vessel, and (3) in total darkness.

Animal	<i>Rana</i>	<i>Palaemonetes</i>	<i>Fundulus</i>	<i>Ameiurus</i>
Condition—With Eyes				
White-wall Vessel	Light	Light	Light	Light
Black-wall Vessel	Dark	Dark	Dark	Dark
Darkness	Mid-dark	Variable	Light	Lightish
Condition—Without Eyes				
White-wall Vessel	Mid-dark	Dark	Mid-dark	Mid-dark
Black-wall Vessel	Mid-dark	Dark	Mid-dark	Mid-dark
Darkness	Mid-dark	Dark	Light	Lightish

obliterated and each form responded the same to the two kinds of environment. The condition in darkness was again diverse. It is clear from these results that the loss of the eyes brings about an almost complete cessation of the characteristic chromatophoral activities. Apparently the eyes are the chief means of initiating these responses, as was long ago maintained by Lister (1859). But they are not the only means to this end, for both eyeless *Fundulus* and *Ameiurus* lighten when placed in darkness, though they do not respond characteristically to different illuminated environments. As was already pointed out, this condition is very pronounced in *Phoxinus*; but what the additional receptor is in this fish and the two studied by us, brain, pineal organ, or skin, has not as yet been finally determined.

The main result, however, is not to be seen in the exceptional peculiarities of the four animals under review, but in their uniform darkening after the loss of the eyes and when in the light. This type of response, which is also characteristic of almost all the animals recorded in Tables 1, 2, and 3, is a most remarkable condition, when one keeps in mind the great diversity of means whereby chromatophoral changes are induced. It suggests at once an underlying uniformity that in the understanding of these changes must be of more significance than the mere machinery of accomplishment.

To our minds, this uniformity lies in the chromatophore itself rather than in the exciting means, neurohumoral or otherwise. Spaeth (1916) some time ago advanced the proposition that melanophores are disguised smooth-muscle cells, a view that emphasized the many striking resemblances between these two types of effectors. But we believe that, notwithstanding these resemblances, chromatophores, including melanophores, have as much individuality as a type of effector as do other like elements, such as gland cells, ciliated cells, and so forth. If any comparison between chromatophores and other types of cells is to be made, it is more justly in the direction of amoeboid cells than in that of smooth-muscle cells. These cells, and even the amoeba itself, have most obvious resemblances to chromatophores. Any one who has watched the movements of particles in the endoplasm of a pseudopod of the amoeba cannot help but have been impressed with the resemblance of this type of movement to that of pigment granules in the process of a melanophore.¹

¹ In this comparison it is not meant to imply that the dispersion and concentration of pigment in a chromatophore is like the extension and withdrawal of pseudopods in the amoeba. The point of resemblance between the two types of cells is in the peculiar movement of the particles within their processes, be these processes temporary or permanent.

This comparison with the amoeba is, we believe, more than a mere superficial resemblance. The views on chromatophoral activation advanced in this paper, together with the general survey of the subject, have led us to conclude that when a chromatophore is released from external control, as for instance by enucleation, it gravitates more or less of itself to a fairly fixed state. This state is one with fully or almost fully dispersed pigment. We do not regard this state as a resting one, for we do not favor the view that there really is such a state in chromatophores. The dispersed chromatophoral state is, in our opinion, comparable to the condition of an amoeba with extended pseudopods. As is well known, when such an animal is vigorously stimulated it responds by the retraction of its pseudopods and becomes approximately spherical in form. This corresponds in our comparison to the condition of a chromatophore with concentrated pigment and might be regarded as representing a state of full activity as contrasted with that of full rest. But, as already stated, we are not inclined to regard any state of the chromatophore as one of rest or activity such, for instance, as can be declared for striped muscle. We regard chromatophores as cells or cell-aggregates which may be excited by external means (neurohumors) to concentrate or to disperse their pigment. When they are freed from external influences they of themselves gravitate, so to speak, to a condition of fully or almost fully dispersed pigment.

If this view of chromatophoral activity is correct two sets of agents must be concerned, on the one hand concentrating and dispersing neurohumors and on the other the innate dispersing action of the chromatophore itself. It follows from this view that the process of pigment dispersion would depend upon two factors one external, a neurohumor, and the other internal, the dispersing activity of the chromatophore, while pigment concentration would be excited by only a single external factor, a neurohumor. It is remarkable that in the few instances where the processes of pigmentary concentration and of dispersion have been timed, dispersion, the process assumed to be under double control, is more rapid than concentration, that assumed to be under a single agent.² These observations on the times

² The time necessary for pigment concentration and pigment dispersion in chromatophores has been determined for *Anolis* by Carlton (1903), for *Phry-*

involved in change, still further disposed us to look with favor on the scheme of pigment concentration and dispersion suggested by us in this paper. They do not, however, lead us to designate any condition of the chromatophore as especially one of rest or of activity, as may be done with cross-striped muscle. Such distinctions are in our opinion inappropriate for chromatophores.

SUMMARY.

1. Eyeless specimens of *Rana pipiens*, of *Palaemonetes vulgaris*, of *Fundulus heteroclitus*, and of *Ameiurus nebulosus* quickly attain a dark coloration and in the light retain this tint irrespective of the environment.

2. This dark condition is true of the majority of other eyeless amphibians, crustaceans, and fishes under like conditions.

3. In darkness eyeless *Rana* and *Palaemonetes* are of the same tint as in the light, but *Fundulus* and *Ameiurus* assume a lighter shade, showing that there must be some other element than the eye that influences their chromatophores.

4. The concentration of pigment in chromatophores is believed to be due to one factor, a concentrating neurohumor; its dispersion to two, a dispersing neurohumor and the innate action of the chromatophore itself.

5. Chromatophores, unlike striped muscle, exhibit no state that may be rightly called a state of rest, as opposed to one of activity.

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osoma by Parker (1906), for *Fundulus* by Parker (1934), and for *Mustelus* by Parker and Porter (1934) as follows:

	Concentration	Dispersion
Anolis	25 min.	4 min.
Phrynosoma	30 min.	15 min.
Fundulus	4.6 hrs.	1.8 hrs.
Mustelus	48 hrs.	2 hrs.

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VOL. 69. No. 13.—FEBRUARY, 1935.

RECORDS OF MEETINGS, 1933-1934.

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RECORDS OF MEETINGS.

One Thousand Two Hundred and Seventh Meeting.

OCTOBER 11, 1933.—STATED MEETING.

The Academy met at its House at 8.25 P. M.

The PRESIDENT in the Chair.

There were present seventy-nine Fellows and sixteen guests.

The records of the meeting of May 10 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from Gordon W. Allport, Philip Bard, Harold K. Barrows, William N. Bates, George H. Bigelow, Harry A. Bigelow, Henry W. Biklé, George H. Blakeslee, Campbell Bonner, Edwin M. Borchard, Charles F. Brooks, Carleton Brown, Harold H. Burbank, Benjamin N. Cardozo, Frank M. Carpenter, James McKeen Cattell, Charles Collens, Robert T. Crane, Cyrus E. Dallin, Alden B. Dawson, John Dickinson, Jesse Douglas, Curt J. Ducasse, Carl Engel, Louis F. Fieser, Reginald Fitz, Henry T. Fowler, Sheldon Glueck, Theodore F. Green, Learned Hand, Halford L. Hoskins, Edgar E. Hume, Walter S. Hunter, George B. Kistiakowsky, Hans Kurath, Leo R. Lewis, Frank R. Lillie, Ivan M. Linforth, Lee S. McColester, Edward S. Mason, James V. May, Arthur E. Norton, Howard R. Patch, Carroll C. Pratt, Edward Sapir, Josef A. Schumpeter, George C. Shattuck, David S. Smith, Harlan F. Stone, Marshall H. Stone, William I. Thomas, Henry W. Underwood, Jr., Soma Weiss, Frederic L. Wells, Frank E. Winsor, Harry A. Wolfson, Jeffries Wyman, Jr., Henry A. Yeomans; and of letters accepting Foreign Honorary Membership from Rafael Altamira y Crevea, Gösta A. Bagge, Frantz Dahl, François Geny, Jaroslav Heyrovsky, Sir Arthur Keith, Hans Kelsen, Juljusz Makarewicz, Friedrich Meinecke, Georg E. Müller, Fritz Paneth, Werner Sombart, Hans Spemann, Rudolf Stammeler, Sir Josiah Stamp, and Giorgio Del Vecchio; also of a letter from Arthur Winslow, resigning Fellowship.

The Corresponding Secretary announced that the Council had made the following grants from the Permanent Science Fund:

1. To Charles V. Green, Roscoe B. Jackson Memorial Laboratory, Bar Harbor, Maine, \$500, to aid in his studies of tumor inheritance:

2. To Gleason W. Kenrick, Tufts College, \$500, for apparatus and assistance to aid him in studying the Kennelly-Heaviside Layer:

3. To Bret Ratner, N. Y. U. Bellevue Medical College, New York City, \$500, to assist him in his study of the anaphylactogenic properties of certain materials:

4. To V. M. Slipher, Director of the Lowell Observatory, Flagstaff, Arizona, \$750, to aid in a study of the spectra of the planets.

The President announced the death of six Fellows:—Irving Babbitt (Class IV, Section 4), Arthur Powell Davis (Class I, Section 4), Henry Walcott Farnam (Class III, Section 3), Edward Furber Miller (Class I, Section 4), Arthur Kingsley Porter (Class IV, Section 4), John Eliot Thayer (Class II, Section 3); and of two Foreign Honorary Members:—Robert Seymour Conway (Class IV, Section 3), Viktor Goldschmidt (Class II, Section 1).

The President called attention to the original notification of his election to membership in the Academy sent to Dr. James Thacher, of Plymouth, in 1803, and signed by John Adams as President and John Quincy Adams as Corresponding Secretary, which has been loaned to the Academy by Miss Mary R. Hodge.

The Fellows elected in May were then presented to the Academy.

The following communication was presented:

Mr. Edward V. Huntington: "A Simplified Theory of the Figure of the Earth," illustrated with lantern slides.

Four papers were read by title: "Gyromagnetic Experiments on the Process of Magnetization in Weak Fields," by S. J. Barnett; "The Application of Methods of Geometrical Inversion to the Solution of Certain Problems in Electrical Resonance," by W. G. Cady; "The Lower Permian Insects of Kansas. Part 6," by F. M. Carpenter; "Methods and Procedures used in the Massachusetts Institute of Technology Program of Investigation of the Pressures and Volumes of Water to 460° C.," by F. G. Keyes.

The meeting was dissolved at 9.25 P. M.

One Thousand Two Hundred and Eighth Meeting.

NOVEMBER 8, 1933.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present fifty-six Fellows and six guests.

The records of the meeting of October 11 were read and approved

The Corresponding Secretary announced that the Council had reappointed Mr. J. D. M. Ford for four years as a delegate of the Academy to the American Council of Learned Societies.

He also reported the receipt of letters accepting Fellowship from John Gilbert Beebe-Center, John Alden Carpenter, George Burgess Magrath, Albert Warren Stearns, Abbott Payson Usher, and George Benson Weston; and of a letter declining Fellowship from Charles Herbert Woodbury.

The President announced that the Rumford Medals voted to Dr. Harlow Shapley at the May meeting will be presented to him at an adjourned meeting of the Academy to be held in conjunction with the American Association for the Advancement of Science in December.

The following communication was presented:

Mr. Kenneth J. Conant: "The Monastery at Cluny," illustrated with lantern slides.

Four papers were read by title: "The Rotation of Cobalt and Nickel by Magnetization and the Gyromagnetic Ratios of their Magnetic Elements," by S. J. Barnett; "The Psammocharidae of the Philippines," by Nathan Banks; "The Purification and Physical Properties of Organic Compounds. III. The Specific Heat of Solids just below the Melting Point as a Criterion of Purity," by Evald L. Skau, presented by F. G. Keyes; "The Vapor Pressure of Water. Part 2. Steam Pressure Program," by Leighton B. Smith, Frederick G. Keyes, and Harold T. Gerry.

The meeting was dissolved at 9.50 P. M.

One Thousand Two Hundred and Ninth Meeting.

DECEMBER 13, 1933.—STATED MEETING.

The Academy met at its House at 8.25 P. M.

The PRESIDENT in the Chair.

There were present forty-two Fellows and three guests.

The records of the meeting of November 8 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Dr. Stanley Cobb, resigning Fellowship.

The President announced the death of two Fellows: James Arnold

Lowell (Class III, Section 1) and Lyman Churchill Newell (Class I, Section 3).

The following communication was presented:

Mr. Jerome C. Hunsaker: "Recent Evolution in Airships," illustrated with lantern slides.

Two papers were read by title: "The Synthesis of Ammonia in the Electrodeless Discharge," by Walter C. Schumb and Louis Goldman; "Studies on Histomoniasis, or 'Blackhead' Infection, in the Chicken and the Turkey," by E. E. Tyzzer.

On motion of Mr. A. E. Kennelly the Academy adjourned at 9.25 P. M. to meet on December 30 at the Hotel Statler with the American Association for the Advancement of Science for the presentation of the Rumford Medals to Dr. Harlow Shapley.

One Thousand Two Hundred and Tenth Meeting.

DECEMBER 30, 1933.—ADJOURNED MEETING.

The Academy met in the Ball Room of the Hotel Statler at 8.30 P. M. in conjunction with the American Association for the Advancement of Science.

The PRESIDENT in the Chair.

The President introduced Mr. Arthur E. Kennelly, Chairman of the Rumford Committee, who, after giving an account of the Rumford Premium and stating the grounds on which the present award was made, presented the Rumford Medals to Dr. Harlow Shapley.

Dr. Shapley delivered an address on "The Anatomy of a Disordered Universe."

The meeting then adjourned.

One Thousand Two Hundred and Eleventh Meeting.

JANUARY 10, 1934.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present forty-five Fellows and nine guests.

The records of the meeting of December 13 were read and approved.

The President announced the death of two Fellows: John Candler Cobb (Class III, Section 3) and Everett Morss (Class III, Section 4).

On motion of Mr. Neal, it was

Voted, That the President appoint a committee to consider a proposal made by the Committee on Membership, involving an amendment to the Statutes.

The following communication was presented:

Dr. Elliott C. Cutler: "The Relation of the Thyroid Gland to Disease of the Heart," illustrated with lantern slides.

The meeting was dissolved at 9.40 P. M.

One Thousand Two Hundred and Twelfth Meeting.

FEBRUARY 14, 1934.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present forty-five Fellows and six guests.

The records of the meeting of January 10 were read and approved.

The President reported the receipt of letters resigning Fellowship from William Y. Elliott and Arthur M. Schlesinger.

The President announced the death of William Morris Davis, Fellow in Class II, Section 1, and of Fritz Haber, Foreign Honorary Member in Class I, Section 3.

Mr. Neal, on behalf of the committee appointed by the President, moved that the Statutes be amended so that Article 2 of Chapter II, shall read as follows:

"The number of Fellows shall not exceed Eight hundred, of whom not more than Six hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and twenty in any one Class," (instead of Two hundred and ten).

and it was so *Voted*.

The following communications were presented:

Mr. William Hovgaard: "The Fundamentals of the Theory of Relativity."

Mr. Kirsopp Lake: "Dated Greek Minuscule Manuscripts," illustrated with lantern slides.

The following papers were read by title: "Critical Examination of Physical Anthropometry on the Living," by C. B. Davenport, Morris Steggerda, and William Drager; "The Volumes of Unit Mass of

Liquid Water and their Correlation as a Function of Pressure and Temperature. Part III of the Steam Research Program," by Leighton B. Smith and F. G. Keyes; "The Compressibility of Mercury from 30° to 300° Centigrade. Part III A of the Steam Research Program," by L. B. Smith and F. G. Keyes.

The meeting was dissolved at 9.55 P. M.

One Thousand Two Hundred and Thirteenth Meeting.

MARCH 14, 1934.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present thirty-five Fellows and three guests.

The records of the meeting of February 14 were read and approved.

On the recommendation of the Council the following appropriations were made for the ensuing year:

From the income of the General Fund, \$7,450, to be used as follows:

for General and Meeting expenses	\$ 800
for Library expenses	2,000
for Books, Periodicals, and Binding	1,500
for House expenses	2,200
for Treasurer's expenses	950

From the income of the Publication Funds, \$3,017.77, to be used for publication.

From the income of the Rumford Fund, \$3,230, to be used as follows:

for Research	\$2,000
for Books, Periodicals, and Binding	350
for use at the discretion of the Committee	880

From the income of the C. M. Warren Fund, \$821.75, to be used at the discretion of the Committee.

The President announced the appointment of the Nominating Committee:

Roland G. D. Richardson, of Class I
 Hervey W. Shimer, of Class II
 Roscoe Pound, of Class III
 Albert C. Knudson, of Class IV

The following communications were presented:

Mr. Milman Parry: "Some Processes of Oral Poetic Composition Observable in Southslavonic Heroic Poetry," illustrated with lantern slides.

Mr. B. E. Warren: "Arrangements of Atoms in Liquids and in Glasses," with lantern illustrations.

The meeting was dissolved at 10.10 P. M.

One Thousand Two Hundred and Fourteenth Meeting.

APRIL 11, 1934.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present thirty-one Fellows and eight guests.

The records of the meeting of March 14 were read and approved.

The Corresponding Secretary announced that the Council had made the following grants from the Permanent Science Fund:

1. To J. C. Boyce, Massachusetts Institute of Technology, \$400, for aid in investigating the extreme ultra-violet spark spectra of the rare gases krypton and xenon:

2. To T. T. Chen, University of Pennsylvania, \$90, to permit the publication of three heliotype plates illustrating his monograph on the cytology of Opalinid Ciliate Protozoa:

3. To W. W. Coblentz, U. S. Bureau of Standards, \$400, for expenses in connection with an evaluation of ultra-violet in sunlight at Flagstaff, Arizona:

4. To E. A. Culler, University of Illinois, \$350, for purchasing apparatus to be used in an investigation of the effect upon hearing of protracted exposure to sound-frequencies of high intensity:

5. To J. W. McBain, Stanford University, \$400, for materials and equipment to aid him in determining absorption in the air-water interface:

6. To Charles Palache, Harvard University, \$250, for the technical assistance of R. C. Wells in a study of the chemical composition of the mineral samarskite, especially with respect to its content of uranium, thorium, and lead, as a basis of the determination of geological age:

7. To Gayle Scott, Texas Christian University, \$500, for field

expenses in a study of the stratigraphy and paleontology of the Trinity Group in Texas:

8. To A. F. Shull, University of Michigan, \$300, for expenses in connection with an investigation of the internal and external factors influencing wing production in aphids.

The President announced the death of two Fellows:—Harold Murdock (Class IV, Section 4), and Henry Weeden Underwood, Jr. (Class I, Section 3); and one Foreign Honorary Member:—Francis Arthur Bather (Class II, Section 3).

The following communication was presented:

Mr. Bernard E. Proctor: "The Microbiology of the Upper Air," illustrated with lantern slides.

One paper was read by title: "The Wood-Feeding Roach *Cryptocercus*, its Protozoa, and the Symbiosis between Protozoa and Roach," by L. R. Cleveland.

The meeting was dissolved at 9.45 P. M.

One Thousand Two Hundred and Fifteenth Meeting.

MAY 9, 1934.—ANNUAL MEETING.

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present fifty-four Fellows and three guests.

The records of the meeting of April 11 were read and approved.

The Corresponding Secretary reported that the President had appointed Sir Arthur Keith as the delegate of the Academy at the First International Congress of Anthropological and Ethnological Sciences to be held at London, beginning July 30, 1934.

He also announced the appointment by the President of a Committee on the Disposal of Extra Publications consisting of Messrs. A. C. Lane (Chairman), R. P. Bigelow, H. V. Neal, and Ingersoll Bowditch.

The President announced the death of two Fellows:—LeBaron Russell Briggs (Class IV, Section 4) and William Henry Welch (Class II, Section 4); and of one Foreign Honorary Member:—Archibald Byron Macallum (Class I, Section 3).

The following report of the Council was presented:

REPORT OF THE COUNCIL.

Since the last report of the Council there have been reported the deaths of fifteen Fellows:—Irving Babbitt, LeBaron Russell Briggs, John Candler Cobb, Arthur Powell Davis, William Morris Davis, Henry Walcott Farnam, James Arnold Lowell, Edward Furber Miller, Everett Morss, Harold Murdock, Lyman Churchill Newell, Arthur Kingsley Porter, John Eliot Thayer, Henry Weeden Underwood, Jr., William Henry Welch; and five Foreign Honorary Members:—Francis Arthur Bather, Robert Seymour Conway, Viktor Goldschmidt, Fritz Haber, Archibald Byron Macallum.

Seventy Fellows and sixteen Foreign Honorary Members were elected by the Council and announced to the Academy in May 1933.

The roll now includes 719 Fellows and 116 Foreign Honorary Members (not including those elected in May 1934).

The annual report of the Treasurer, Ingersoll Bowditch, was read, of which the following is an abstract:

GENERAL FUND.

Receipts.

Income on hand April 1, 1933.	\$2,279.92	
From Investments	\$2,594.72	
From Assessments	5,910.00	
From Admissions	430.00	
From Interest on Deposits.	44.35	
From Rumford Fund Income.	200.00	9,179.07 \$11,458.99

Expenditures.

Expenses of Library	\$2,042.00	
Treasurer's Expenses	1,028.29	
Books and Binding.	1,234.34	
General Expenses	899.83	
House Expenses	2,184.67	
President's Expenses	10.00	
Interest on Bonds bought.	67.58	\$7,466.71
Income transferred to Principal	350.00	\$ 7,816.71

PUBLICATION ACCOUNT.

Receipts.

Income on hand April 1, 1933.		\$8,551.98	
From Income—Appleton Fund . . .	\$1,094.19		
From Income—Centennial Fund. . .	1,813.24		
From Authors' Reprints	219.00		
From Sale of Publications.	536.20	3,662.63	\$12,214.61

Expenditures.

Publications.	\$8,271.32		
Vault Rent—part.	10.00	\$8,281.32	
Interest on Bonds bought.	34.86		
Income transferred to Principal . .	117.00	151.86	\$ 8,433.18

RUMFORD FUND

Receipts.

Income on hand April 1, 1933	\$1,568.65		
From Investments	3,381.00	\$ 4,949.65	

Expenditures.

Purchase and Binding of Books . . \$	270.55		
Research	3,340.00		
Transferred to General Fund In-			
come for care of books	200.00		
United States Mint—medals	313.49		
Bigelow, Kennard & Co.—engrav-			
ing medals	15.00	\$4,139.04	
Interest on Bonds bought.	.33		
Income transferred to Principal . .	170.00	170.33	\$ 4,309.37

C. M. WARREN FUND.

Receipts.

From Investments	\$ 1,057.90
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Expenditures.

Income overdrawn	\$ 22.08	
Research	900.00	
Vault rent—part.	3.00	\$ 925.08
Interest on Bonds bought.	59.03	
Income transferred to Principal	52.50	111.53 \$ 1,036.61

FRANCIS AMORY FUND.

Receipts.

Income on hand April 1, 1933.	\$ 639.28
From Investments	2,707.13 \$ 3,346.41

Expenditures.

Publishing Statement	\$ 61.25
Income transferred to Principal	1,973.58
Interest on Bonds bought.	199.51
Premium on Bonds bought	238.10 \$ 2,472.44

PERMANENT SCIENCE FUND.

Receipts.

Received for above fund	\$ 5,800.00
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Expenditures.

Income overdrawn.	\$ 225.00
Grants from above fund	4,575.00 \$ 4,800.00

The following reports were also presented:

REPORT OF THE LIBRARY COMMITTEE.

During the year 154 volumes and thirty-seven unbound numbers of periodicals have been borrowed by twelve Fellows and eighteen

libraries, and more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for.

The number of volumes on the shelves at the time of the last report was 43,517. During the year 429 volumes were added, largely by binding serials, making the number now 43,946. This includes 45 purchased from the General Fund, 27 from the Rumford Fund, and 357 received by gift or exchange.

The following appropriations were placed at the disposal of the Librarian during the past year:

Balance from General Fund.	\$ 305.95
Balance from Rumford Fund	81.47
Appropriation from General Fund.	3,400.00
Appropriation from Rumford Fund	350.00
Total	<u>\$4,137.42</u>

The expenses charged to the library during the financial year ending March 31, 1934, were:

Salaries	\$2,000.00
Binding:	
General Fund	631.20
Rumford Fund	67.25
Total	<u>\$ 698.45</u>

Purchase of Books and Periodicals:

General Fund.	\$ 603.14
Rumford Fund	203.30
Total	<u>\$ 806.44</u>
Miscellaneous	42.00
Total	<u>\$3,546.89</u>

There remained an unexpended balance of \$590.53, as follows:

General Fund.	\$ 429.61
Rumford Fund	160.92
Total	<u>\$ 590.53</u>

As usual, this balance will be carried over to next year. The balance is larger than usual because the 1934 subscriptions to German

periodicals were not paid until after the close of the fiscal year. But difficulties of exchange make the amount needed unusually uncertain. Mrs. M. F. Ball, assistant librarian, has continued to faithfully and efficiently perform her varied duties.

Respectfully submitted,

ALFRED C. LANE, *Librarian.*

May 9, 1934.

REPORT OF THE RUMFORD COMMITTEE.

The Rumford Committee held three meetings during the academic year April 1, 1933–March 31, 1934, on April 12, May 10, and November 8, 1933.

The Committee made the following grants, during the year, from the Rumford Fund in aid of researches in light and heat:

<i>1933</i>	<i>No.</i>		<i>Amount</i>
Apr. 12	305	Prof. J. C. Stearns, Denver University, for equipment in continuation of cosmic researches	\$ 300
Apr. 12	306	Prof. G. W. Kenrick, Tufts College, toward equipment in extension and continuation of his researches on the effects of solar radiation on the ionised layers	500
May 10	307	Prof. W. J. Luyten, University of Minnesota, for equipment in astrophotometric research	50
Nov. 8	308	Prof. N. A. Kent, Boston University, for equipment for luminous wave length researches	250
Nov. 8	309	Dr. C. E. Teeter, Jr., 109 Maple St., Waverly, Mass. for equipment for research on thermal properties of gases	250
Nov. 8	310	Dr. Jan Schilt, Columbia University, for photo-electric equipment for astronomical measurements	200
Nov. 8	311	Prof. Joel Stebbins, University of Wisconsin, for equipment in astronomical research	300
Nov. 8	312	Prof. G. R. Harrison, Mass. Institute of Tech., for equipment in spectroscopic research	400

1934	No.		Amount
Mar. 17	313	Prof. A. G. Worthing, University of Pittsburgh, for equipment in research on properties of matter at high temperatures . . .	350
Total			\$2,600

As stated in last year's report (May 1933), the Rumford Committee recommended to the Academy Council the award of the Rumford Medal to Prof. Harlow Shapley, Director of the Harvard Observatory, "for researches in the luminosities of stars and galaxies." The Medal was awarded at a joint meeting of the Academy with the American Association for the Advancement of Science (AAAS), in the Statler Hotel, on the evening of Saturday, December 30, 1933.

The following recent publications concerned researches that have been aided by Rumford grants:

"Magnetic Rotation Spectrum of the Red Bands of Sodium," by W. R. Fredrickson and C. R. Stannard. Grant No. 292. *Physical Review*, October 15, 1933, pp. 632-637.

"The Compressibility of Eighteen Cubic Compounds," by P. W. Bridgman. Grant No. 293. *Proc. Am. Acad. of Arts & Sciences*, Vol. 67, No. 9, December 1932.

"Compressibilities and Pressure Coefficients of Resistance of Elements, Compounds, and Alloys, Many of Them Anomalous," by P. W. Bridgman. Grant No. 293. *Proc. Am. Acad. of Arts & Sciences*, Vol. 68, No. 2, March 1933.

"The Pressure-Volume-Temperature Relations of Fifteen Liquids," by P. W. Bridgman. Grant No. 293. *Proc. Am. Acad. of Arts & Sciences*, Vol. 68, No. 1, March 1933.

Respectfully submitted,

A. E. KENNELLY, *Chairman*.

May 9, 1934.

REPORT OF THE C. M. WARREN COMMITTEE.

The Committee had at its disposal at the beginning of the fiscal year 1933-1934, \$934.37, of which \$903 has been appropriated during the past year, leaving a balance of \$31.37.

Since the last annual report grants have been made as follows:

June 2, 1933: To Professor Henry F. Gilman, Iowa State University, \$300, for the purchase of special chemicals to be used in the study of the relative reactivities of organo-metallic compounds.

June 2, 1933: To Professor Paul L. Kirk, Medical School, University of California, \$260, for the purchase of the equipment of a petrographical microscope to be used in the determination of crystallographic and optical constants of amino acid derivatives.

June 30, 1933: To Professor Richard C. Tolman, California Institute of Technology, \$440, to pay for the services of an assistant in the study of the homogeneous bimolecular reaction between acetyl chloride and methyl alcohol in the gas phase and in solution.

Reports of progress, during the current year, have been received from C. F. H. Allen, William Lloyd Evans, Henry F. Gilman, Ernest H. Huntress, C. R. Johnson, G. B. Kistiakowsky, Nelson K. Richtmyer, Hermann Schmid, and Evald Skau.

Six applications for grants totaling \$1,900 are before the Committee for consideration at its next meeting.

The papers listed below, which have been published since the last report of the Committee, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

C. F. H. Allen and E. W. Spanagel:

"The Reactions of Anhydracetonebenzil. II." *J. Am. Chem. Soc.*, **55**, 3773 (1933).

C. F. H. Allen and H. W. J. Cressman:

"Addition Reactions of Vinyl Phenyl Ketone. III. Methyl Malonate." *J. Am. Chem. Soc.*, **55**, 2953 (1933).

Gale Francis Nadeau, Mildred Ratliff Newlin, and William Lloyd Evans:

"The Mechanism of Carbohydrate Oxidation, XVI. The Action of Aqueous Solutions of Potassium Hydroxide on 1-Rhamnose." *J. Am. Chem. Soc.*, **55**, 4957 (1933).

Nelson K. Richtmyer:

"The Cleavage of Glycosides by Catalytic Hydrogenation" (Title of paper presented by Professor Richtmyer before the Organic Division of the American Chemical Society at St. Petersburg. Additional experiments have been performed and the completed work is to be prepared for publication very soon.)

Herren H. Schmid and E. Gastinger-Wien:

"Spektralphotometrie Kurzlebiger Zwischenprodukte." *Ztschr. Elektrochem.* Bd. 39, 573, Nr. 7b. (1933).

Greenstein, Jesse P. (Grant to Carl L. A. Schmidt):

"III. The Apparent Dissociation Constants, Free Energy Changes, and Heats of Ionization of Peptides Involving Arginine, Histidine, Lysine, Tyrosine, and Aspartic and Glutamic Acids, and the Behavior of Lysine Peptides toward Nitrous Acid." *Journal of Biological Chemistry*, 101, (3), August, 1933.

Evald L. Skau:

"The Purification and Physical Properties of Organic Compounds. II." *The Journal of Physical Chemistry*, 37, (5), May, 1933.

Evald L. Skau and Wendell H. Langdon:

"The Purification and Physical Properties of Chemical Compounds. IV." *Proceedings of the National Academy of Sciences*, 19, (11), 943-947, November, 1933.

Evald L. Skau and I. Laird Newell:

"A Rapid Volumetric Method for Determination of Sulfur in Coal and Coke." *Industrial and Engineering Chemistry*, 5, 180, May 15, 1933.

JAMES F. NORRIS, *Chairman*.

May 9, 1934.

REPORT OF THE COMMITTEE OF PUBLICATION.

During the year three meetings of the Committee of Publication have been held. At its meeting of December 6 the committee approved the suggestion of Dr. E. B. Wilson that subscribers to the publications of the Academy be granted the privilege of buying at reduced cost a duplicate set of the publications. At the meeting of March 14 the committee voted to let the contract for printing and binding the Cleveland memoir (Vol. 17, Part 2) to the George Banta Publishing Company, whose bid was the lowest received. As usual, for financial reasons, the committee has been obliged to decline for publication manuscripts by non-members.

Since the last report of the committee fifteen numbers of the Proceedings have been printed and distributed. These include numbers 6 to 13 of Volume 68 and 1 to 7 of Volume 69. In accordance with the recommendation of the Council, the Records number of the Proceed-

ings has been mailed to all members. The Cleveland memoir and the first fascicle of Professor Lake's Corpus of Dated Greek Minuscule Manuscripts will be off the press this month.

The financial report is as follows:

Receipts.

Balance April 1, 1933	\$ 8,302.09
Balance Rumford Fund Account	249.89
Appropriation for 1933-34.	2,223.00
Receipts from sales and reprints	<u>755.20</u>
Total available for publication 1933-34	\$11,530.18

Expenses.

Printing, Engraving and Binding.	\$ 7,780.05
Mailing and cartage	491.27
Rental safety deposit box.	<u>10.00</u>
Total	\$ 8,281.32
Balance carried over to 1934-35	\$ 3,248.86

The Committee of Publication wishes to express to the Committee on the Permanent Science Fund appreciation of its generous appropriation of \$500 towards the expense of the Cleveland memoir. Grateful acknowledgment is also made of the gift of \$2,000 contributed by the American Council of Learned Societies towards the cost of publication of the Corpus of Dated Greek Minuscule Manuscripts edited by Professor Kirsopp Lake and Mrs. Silva Lake.

Respectfully submitted,

H. V. NEAL, *Chairman.*

May 9, 1934.

REPORT OF THE HOUSE COMMITTEE.

The House Committee has had funds at its disposal amounting to \$3,096.57, made up as follows:

Balance from previous year.	\$ 406.57
Appropriations for 1933-34.	2,500.00
Received for use of rooms	<u>190.00</u>
Total	\$3,096.57

Of this amount the sum of \$2,272.50 has been spent for the routine expenses,—janitor, light, power, heat, telephone, etc., and \$102.17 has been spent for upkeep and equipment; making a total of \$2,374.67, and leaving an unexpended balance of \$721.90.

Meetings have been held as follows:

The Academy	8
American Antiquarian Society	1
American Chemical Society, Northeastern Section	8
Archæological Institute of America, Boston Society	3
Japan Society of Boston	3
Mediaeval Academy of America.	1
New England Botanical Club	9
	—
Total	33

The Council Chamber has been used for Academy Council and Committee meetings, and also by the Trustees of the Children's Museum, the New England Farm and Garden Association, etc.

A detailed list of expenditures follows:

Janitor	\$ 968.00
Electricity: Light	260.25
Power.	70.44
Fuel.	616.17
Elevator	99.05
Gas	68.10
Telephone	112.02
Water	51.52
Ash tickets.	14.85
Upkeep.	100.37
Furnishing and equipment	1.80
Janitor's supplies and sundries	12.10
Total	\$2,374.67

Respectfully submitted,

S. BURT WOLBACH, *Chairman.*

May 9, 1934.

On motion of Mr. E. A. Whitman, seconded by Mr. A. C. Lane, it was *Noted*, To refer to the House Committee the getting of an estimate

for improvement of the acoustics and ventilation of the Lecture Hall of the Academy.

On the recommendation of the Treasurer, it was *Voted*, That the annual assessment for the ensuing year be \$10.00.

The annual election resulted in the choice of the following officers and committees:

GEORGE HOWARD PARKER, *President*
 JAMES FLACK NORRIS, *Vice-President for Class I*
 WALTER BRADFORD CANNON, *Vice-President for Class II*
 EDWIN FRANCIS GAY, *Vice-President for Class III*
 ARTHUR STANLEY PEASE, *Vice-President for Class IV*
 TENNEY LOMBARD DAVIS, *Corresponding Secretary*
 WALTER EUGENE CLARK, *Recording Secretary*
 INGERSOLL BOWDITCH, *Treasurer*
 ALFRED CHURCH LANE, *Librarian*
 ROBERT PAYNE BIGELOW, *Editor*

Councillors for Four Years.

WILLIAM C. GRAUSTEIN, of Class I JOSEPH H. BEALE, of Class III
 KIRK BRYAN, of Class II EDGAR S. BRIGHTMAN, of Class IV

Finance Committee.

THOMAS BARBOUR PAUL J. SACHS ALFRED L. RIPLEY

Rumford Committee.

ARTHUR E. KENNELLY
 ELIHU THOMSON HARRY M. GOODWIN HARLOW SHAPLEY
 PERCY W. BRIDGMAN CHARLES L. NORTON NORTON A. KENT

C. M. Warren Committee.

JAMES F. NORRIS
 GREGORY P. BAXTER ARTHUR D. LITTLE REID HUNT
 WALTER L. JENNINGS FREDERICK G. KEYES CHARLES A. KRAUS

Committee of Publication.

ROBERT P. BIGELOW, *Chairman*
 EDWIN C. KEMBLE, of Class I JOSEPH H. BEALE, of Class III
 FREDERIC T. LEWIS, of Class II ROBERT P. BLAKE, of Class IV

*Committee on the Library.*ALFRED C. LANE, *Chairman*

RAYMOND C. ARCHIBALD, of Class I NATHAN ISAACS, of Class III

THOMAS BARBOUR, of Class II HENRY B. WASHBURN, of Class IV

Auditing Committee.

GEORGE R. AGASSIZ

ALEXANDER FORBES

*House Committee.*S. BURT WOLBACH, *Chairman*

WILLIAM H. LAWRENCE ROBERT P. BIGELOW DAVIS R. DEWEY

*Committee on Biographical Notices.*DAVIS R. DEWEY, *Chairman*

JAMES F. NORRIS

JOSEPH H. BEALE

ALFRED C. LANE

WALTER E. CLARK

SAMUEL E. MORISON

Committee on Meetings.

THE PRESIDENT

THE RECORDING SECRETARY

DANIEL F. COMSTOCK

LEIGH HOADLEY

CHARLES J. BULLOCK

JOSHUA WHATMOUGH

The Corresponding Secretary announced that the following had been elected members of the Academy:

FELLOWS.

CLASS I.

- Section 1.* Griffith Conrad Evans, Houston, Texas
 Donald Howard Menzel, Cambridge
- Section 2.* Franzo Hazlett Crawford, Cambridge
 Louis Williams McKeegan, New Haven, Conn.
 Harry Rose Mimno, Cambridge
 Philip McCord Morse, Cambridge
 Leigh Page, New Haven, Conn.
 John Hasbrouck Van Vleck, Madison, Wis.

- Section 3.* Leighton Bruerton Smith, Beverly
David Elbridge Worrall, Tufts College
- Section 4.* Otto Gustav Colbiornsen Dahl, Brookline
Chester Laurens Dawes, Cambridge
Jacob Pieter Den Hartog, Wellesley Hills
Jerome Clark Hunsaker, Cambridge
Edward Leyburn Moreland, Wellesley

CLASS II.

- Section 1.* Sterling Price Fergusson, Milton
Walter Harry Newhouse, Cambridge
Carl-Gustaf Arvid Rossby, Hingham
- Section 2.* Edgar Anderson, Jamaica Plain
Donald Forsha Jones, New Haven, Conn.
Edmund Ware Sinnott, New York, N. Y.
Gilbert Morgan Smith, Stanford University, Cal.
- Section 3.* Cyrus Hartwell Fiske, Belmont
John Farquhar Fulton, New Haven, Conn.
Hudson Hoagland, Worcester
Alfred Newton Richards, Philadelphia, Pa.
Oscar Riddle, Cold Spring Harbor, N. Y.
- Section 4.* Henry Jackson, Jr., Chestnut Hill
Leroy Matthew Simpson Miner, Newtonville
William Carter Quinby, Brookline
Arthur Hiler Ruggles, Providence, R. I.

Class III.

- Section 2.* Edgar Stephenson Furniss, New Haven, Conn.
Alfred Emanuel Smith, New York, N. Y.
- Section 3.* John Maurice Clark, New York, N. Y.
Winthrop More Daniels, New Haven, Conn.
John Franklin Ebersole, Belmont
Ralph Evans Freeman, Cambridge
Robert Murray Haig, New York, N. Y.
Albert Galloway Keller, New Haven, Conn.
Edwin Walter Kemmerer, Princeton, N. J.
Frank Hyneman Knight, Chicago, Ill.
Robert Morison MacIver, New York, N. Y.

- Richard Stockton Meriam, South Lincoln
 Harry Alvin Millis, Chicago, Ill.
 Arthur Eli Monroe, Cambridge
 Edwin Griswold Nourse, Washington, D. C.
 Sumner Huber Schlichter, Cambridge
 Frederick John Teggart, Berkeley, Cal.
 Jacob Viner, Chicago, Ill.
 Leo Wolman, Washington, D. C.
 Carle Clark Zimmerman, Winchester
Section 4. Matt Bushnell Jones, Newton Center
 Henry Plimpton Kendall, Walpole
 Clarence Cook Little, Bar Harbor, Maine
 Erwin Haskell Schell, Cambridge
 Charles Franklin Thwing, Cleveland, Ohio

CLASS IV.

- Section 1.* Kurt Koffka, Northampton
 Lewis Madison Terman, Stanford University, Cal.
 Edward Lee Thorndike, New York, N. Y.
Section 2. Clarence Gordon Campbell, New York, N. Y.
 Robert Henry Pfeiffer, Cambridge
 David Moore Robinson, Baltimore, Md.
 Theodore Leslie Shear, Princeton, N. J.
 Lawrence Counselman Wroth, Providence, R. I.
Section 3. Austin Morris Harmon, New Haven, Conn.
 Roland Grubb Kent, Philadelphia, Pa.
 William Abbott Oldfather, Urbana, Ill.
Section 4. Charles Jay Connick, Newtonville
 Samuel Foster Damon, Providence, R. I.
 Eugene Edward Speicher, New York, N. Y.

FOREIGN HONORARY MEMBERS.

CLASS I.

- Section 1.* Ronald Aylmer Fisher, London
Section 3. Richard Willstätter, Munich
Section 4. Paul Janet, Paris
 Luigi Lombardi, Rome

CLASS II.

Section 1. Arthur Holmes, Durham

Section 3. Archibald Vivian Hill, London

CLASS III.

Section 3. Gustav Cassel, Stockholm

Peter B. Struve, Belgrade

CLASS IV.

Section 4. Serge Koussevitzky, Paris

The following communication was presented:

Mr. Abbott Payson Usher: "Social Evolution and Historical Process," illustrated with lantern slides.

One paper was read by title: "Magnetic Formulas Expressed in the M. K. S. System of Units," by A. E. Kennelly.

The meeting was dissolved at ten P. M.

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IRVING BABBITT (1865-1933).

Fellow in Class IV, Section 4, 1921.

Irving Babbitt, who died in Cambridge on July 5, 1933, was essentially a crusader. Early convinced that it was his duty to combat pernicious error and ignorance, he made it his life work to maintain, with all the resources of learning, eloquence, and wit, the staid doctrine of Humanism, as opposed to purposeless Flux and Naturalism. Thus he became the acknowledged champion of the Humanists in this country, highly appreciated both here and abroad. For a long while he had as a fellow-worker Paul Elmer Moore, once his companion in graduate work. In the opinion of the Humanist school, America (as, indeed, the whole world) suffers from absence of real criticism, due to the lack of permanent standards. Such standards, and the criticism that depends on them, Babbitt strove with all his might and main to inculcate. During his career he was led to oppose violently the philosophical tenets most in vogue—Pragmatism, Bergsonism and the school of John Dewey. Always a formidable antagonist, he aroused much opposition while making, especially among younger men, a considerable number of disciples. Never deterred, he pursued his relentless course unfalteringly, forcefully, patiently carrying on the long tradition of Humanism, by which he meant the doctrine of the distinct and unique position of man in the universe—man, in whom the material and the spiritual meet; man, responsible to a law superior to himself, which we can and must discover by means of our higher imagination. Not a reactionary (though often so described) he recognized the necessity of constant change, but he saw behind all changes certain unchanging principles which should guide us in our literary criticism and in all our philosophical thought. We have been caught, he believed, in the trap of Naturalism, which confuses the law of man and the law of things; from that fatal confusion it is the business of Humanism to extricate us. Against Romanticism, which substitutes caprice and unbridled sentimentalism for stable judgment, and against the great exponent of Romanticism, J. J. Rousseau, he waged ceaseless war. Never did he shrink from hostility to those, living or dead, whom he regarded as perniciously in the wrong. Therein may be found the answer to the question once asked by one of his intelligent students: "Why does Professor Babbitt

always give courses about people whom he hates?" For in his system it was necessary that blame should usually prevail over praise.

Babbitt was born in Dayton, Ohio, on August 2, 1865, obtained a Harvard A.B. in 1889, and then for a brief period taught Greek in Montana. After spending 1891 and 1892 in Paris in the study of Oriental languages, he received in 1893 a Harvard A.M. Later, in 1912, Bowdoin gave him the honorary degree of L.H.D. A short term in Williams as instructor in Romance Languages in 1893-94 was followed, in 1894, by an instructorship in French at Harvard; in 1902 he became assistant professor of French and in 1912 he was promoted to a full professorship in French Literature. Although he continued until the end to belong to the Romance Department, the most important part of his work was in Comparative Literature. In considerable demand at other institutions, he gave lectures at Kenyon College, at Yale, at North Carolina, at Amherst, at Toronto, at Stanford University. In 1923 he was Harvard Exchange Professor in Paris. He was a Fellow of the American Academy of Arts and Sciences and of the American Academy of Arts and Letters, an honorary member of the Phi Beta Kappa, and a *correspondant* of the Institut de France. Between 1898 and 1910 he edited works of Taine, Renan, Voltaire, and Racine. The first of his own writings to appear was *Literature and the American College*, 1908. Then came, from 1910 to 1929, *The New Laokoön*, *The Masters of Modern French Criticism*, *Rousseau and Romanticism*, *Democracy and Leadership*.

C. H. GRANDGENT.

BERNARD ARTHUR BEHREND (1875-1932).

Fellow in Class I, Section 4, 1917.¹

In the death of Dr. B. A. Behrend on March 25, 1932, the Academy lost a distinguished member who was actively associated with electrical engineering for over three decades. Had the art lacked boldness and originality such as characterized his contributions to the design of electric machinery during this period, it is no exaggeration to say that the industry would have been retarded in reaching its present

¹ For data regarding Dr. Behrend's life and personality the writer is indebted to the kind suggestions of Mrs. Behrend and Mrs. Katharine Maynard, in addition to knowledge derived from personal acquaintance.

development. Thus electrical engineering owes a debt to Dr. Behrend for his conspicuous part in maintaining initiative and originality in the field. Ideas and concepts which he brought forward as a young man became guiding principles of succeeding designers, and many of his proposals which at first were rejected as "radical" or "revolutionary" were ultimately adopted as standard thought and practice.

Dr. Behrend was born at Villeneuve, Switzerland, on May 9, 1875, the youngest son among many children. His family was long identified with the paper business, including the Hammermill Paper Company in Germany and in Erie, Pa., but the youngest Behrend from his earliest years was interested in the science of electricity.

Because of his precocity his education was for the most part self-directed and informal. After his first early training under an English tutor he attended educational institutions in Germany, France, and England as a special student, following his natural bent, and studying at will under chosen leaders of scientific thought. Among these were Helmholtz and Kundt of the University of Berlin and Riedler, Slaby, and Kapp of the Technische Hochschule. Darmstadt gave him the honorary degree of Doctor of Engineering in 1931.

Early professional experience was acquired with the Oerlikon Company in Switzerland, and with Gisbert Kapp with whom he lived and worked in England. He was on terms of easy intimacy with the families of Huxley and Sir Oliver Lodge, and developed a strong *anglophile* tendency. Coming to America in 1898, however, he applied for citizenship, and to the end of his life his best energies were devoted to the development of electrical engineering in this country.

Before forming permanent business connections here, Behrend in 1899 gave a series of lectures on alternating-current design at the University of Wisconsin at the invitation of the writer of this memoir, and the material of those lectures formed the basis of his well-known book, "The Induction Motor, its Theory and Design," published in 1901. He joined the staff of the Bullock Electrical Manufacturing Company in 1900, became chief engineer, and built their first turbo-alternator, which won a grand prize at the Louisiana Purchase Exposition in 1904 and brought its designer a gold medal. The largest power unit of the exposition, a 96-pole, 3500 kw. alternator, was also designed by him, and, because of its dependability in that uncertain day, came to be known as "Old Reliable."

With the consolidation of the Bullock Company with the Allis-Chalmers Manufacturing Company, Dr. Behrend became head of their combined electrical departments, and in that post directed the designing and construction of many large alternating-current generators, some of which were driven by hydraulic turbines and some by steam turbines, and a notable proportion of which possessed record-making qualities. He also designed large gas-engine-driven sets for several steel companies.

In 1908 the Westinghouse Electric and Manufacturing Company invited him to organize a similar department at East Pittsburgh and this he successfully accomplished. On account of the unfavorable climate he spent only two years in Pittsburgh, but continued to advise the company after he had opened offices as a consulting engineer in Boston.

The following are some of Dr. Behrend's more important engineering achievements: In the summer of 1895, when twenty years old, he demonstrated the circle diagram for the induction motor, publishing his proof in January 1896 after actual trials had verified its soundness; he developed a successful theory of regulation of alternators under inductive loads; designed the radial-slot rotor for turbo-generators, with chrome nickel end rings; with Ralph D. Mershon he brought about the first successful large-station inter-connection between Lachine Rapids and Shawinigan Falls; he employed very light fly-wheels for the first time in the parallel operation of large gas-engine-driven alternators; and developed the plate rotor construction still used by the Westinghouse Company for its largest turbine-driven machines. He was granted over 80 patents, most of which were assigned to the companies which he represented. In 1912, for improvements in high-speed electric generators, he was given the John Scott medal of the Franklin Institute.

During all these years of active engineering practice he pursued as a personal hobby the making of fine instruments for precision measurements. Although many of these—developed wholly at his own expense—were later adopted as standard articles of production, he was satisfied to have perfected a needed tool for his own experiments, and made no claim for compensation from the manufacturers.

Other hobbies which engrossed his attention were book-collecting and studies of early American furniture and American Colonial

architecture. Of books he bought widely in the field of Americana and *belles-lettres* as well as in science, and at one time owned what was reputed to be the finest collection of Thackeray in America, which Lady Ritchie helped him to assemble. He built a notable example of English domestic architecture in Brookline, and restored with great fidelity an early American house in Longwood.

Dr. Behrend was a fellow of the American Institute of Electrical Engineers; the American Association for the Advancement of Science; the American Physical Society; the American Academy of Arts and Sciences; and a member of the American Society of Civil Engineers; the American Society of Mechanical Engineers; the Institution of Electrical Engineers (Great Britain); the Franklin Institute; and the Society for the Preservation of New England Antiquities.

Numerous important technical papers witness to the activity of his mind and the value of his many inventions. In 1921 he brought out a second edition of his book under the enlarged title, "The Induction Motor and other Alternating Current Motors," dedicating it "To the great pioneers who have been my friends, Nikola Tesla, Gisbert Kapp, André Blondel, C. E. L. Brown."

This note of strong personal attachment was characteristic of the man. Of retiring disposition and frail health, he was little known to the general public, but to his intimates he was a cherished companion of rare mental vigor and keen humor. Ever inclined to take the part of the individual against the group, it was natural that he should defend with warmth the claims of Oliver Heaviside to wider recognition. As senior vice-president of the American Institute of Electrical Engineers he was instrumental in having its honorary membership conferred upon Heaviside, and used his good offices in persuading Heaviside to accept it. A portion of Heaviside's library, bought by Dr. Behrend in the settlement of the estate, has recently been on exhibition at the Massachusetts Institute of Technology.

Among the scientists Thomas Henry Huxley was his revered mental master, and the portrait of Huxley now hanging in our Academy lecture room was executed for Dr. Behrend by the Honorable John Collier, and presented to the Academy in 1930. This is a replica of the portrait painted for Mr. Henry Huxley, and of which an additional replica hangs in the National Portrait Gallery in London.

In 1926 Dr. Behrend married Miss Margaret F. Chase, whose

devotion lightened the increasing burden of ill-health in his later years. His last residence in Wellesley Hills, designed largely by himself, became a center of true hospitality and philosophic discussion. It contained a working laboratory and half a mile of book shelves, thereby reflecting the personality of its owner, who was a man of discriminating taste as well as a scientist, scholar and engineer. He had a notable philosophical cast of mind and a characteristic wit which made him a stimulating companion for all who truly cultivated his acquaintance.

DUGALD C. JACKSON.

Selected Titles from among the Writings of

Dr. B. A. Behrend.

- 1900 On the mechanical forces in dynamos caused by magnetic attraction. A. I. E. E. Trans. 17: 617-26 (Discussion 627-33), 1900.
The factors which determine the design of monophase and polyphase generators. El. World and Engr. 35: 90-92, 125-27, 166-68, Jan. 20-Feb. 3, 1900.
The Induction motor. El. World and Engr. 36: 676 ff. Nov. 3-Dec. 29, 1900. (A Series of articles forming the basis of the book published in 1901.)
- 1901 The induction motor. A short treatise on its theory and design, with numerous experimental data and diagrams. N. Y., Electrical World and Engineer, 1901. 105 p.
- 1903 The experimental basis for the theory of the regulation of alternators. A. I. E. E. Trans. 21: 497-517, 1903.
An improved method of testing large alternators under full load conditions. El. World and Engr. 42: 715-16, 802-03, Oct. 31, Nov. 14, 1903.
- 1907 Introduction to discussion on the practicability of large generators wound for 22,000 volts. A. I. E. E. Trans. 26: 351-56 (Discussion 357-95), 1907.
- 1908 A new large generator for Niagara Falls. A. I. E. E. Trans. 27: 1057-68, 1908.
- 1921 The induction motor and other alternating current motors: their theory and principles of design. Second edition. N. Y.: McGraw-Hill, 1921. 23-272 p.

CHARLES FRANCIS BRUSH (1849-1929).

Fellow in Class I, Section 4, 1917.

The first time I saw Mr. Charles F. Brush was at the International Electrical Exhibition held in Philadelphia in the autumn of 1884. The Brush Electric Company which he had founded in Cleveland, Ohio, for the development, manufacture, and sale of electrical machinery and other equipment was one of the exhibitors in the Exhibition, and Mr. Brush appeared before my college-student eyes as a member of an exhibitor group comprising Edison, Elihu Thomson, Edward Weston, Frank Sprague, Vandepoele, William Stanley, and others who likewise were associated with exhibits in that Exhibition. Brush had invented the differential arc-lamp six years earlier and thereby made feasible the simultaneous operation of many arc-lamps fed in a series on one electrical circuit from the generator. He also had invented electric generators and motors, lead-cell storage batteries, and other electrical devices. He was rather tall, rather spare, rather serious in mien. Compared with Thomson, Weston, Sprague, Vandepoele, and even with Edison, whose personal exhibit was under the direction of William J. Hammer, Brush gave little attention to his exhibit in this pioneer American electrical exhibition. He apparently found that his workshop in Cleveland contained interests more to his tastes than intimate association with his fellow inventor-exhibitors and contact with the flocking exhibition visitors. Nevertheless, Mr. Brush was a man of friendly and hospitable instincts and he practiced at his home a quiet hospitality that was appreciated in Cleveland.

Born in Euclid township, Cuyahoga County, Ohio, on March 17th, 1849, he was the son of an early manufacturer of woolen products who had moved to Ohio to engage in farming. The boy early became enflamed with an interest in electrical devices and is said to have planned at the age of 15 an electrical arrangement for turning gas street-lamps on and off in groups. In any event, his graduating essay at the Cleveland High School in 1865 was on dynamos and arc lights, regarding which some information had come to this country as news of Mr. Wilde's experiments in England. In those days there was no such rich range of choice among engineering curricula in the colleges as is now available to young high-school graduates. Indeed, but few curricula of engineering of any kind then existed in the colleges. The

University of Michigan offered the opportunity of engineering study and Mr. Brush graduated from that University as a mining engineer in 1869. From this start it was natural for his earliest employment to be in work as a chemical expert and from that to drift into the business of merchant for metals and ores.

However, the lure of electrical machinery maintained its hold and by 1876 he was designing and supervising the construction of a dynamo. In 1877 he retired from other employment in order that he might devote himself wholly to investigation and experimentation related to possibilities for producing light by means of the electric current. His progress was rapid. One of the earliest Brush arc-light dynamos was exhibited operating arc-lamps at the Charitable Mechanics' Fair in Boston in 1878. A dynamo along with perhaps one or two arc-lamps was shown and tested at the Franklin Institute in Philadelphia a year or so earlier. The differential arc-lamp and the disc clutch had been invented in the interval and arc-lighting had been established on a practicable basis. The Brush arc-light system was adopted for street lighting by the City of Cleveland in 1878 and was soon recognized and used all over the world. The Brush Electric Company was incorporated and established in Cleveland in 1881. An associated British company in that year exhibited the Brush dynamo and arc-lighting system at the International Electrical Exposition in Paris (France) and this brought to Mr. Brush the decoration of Chevalier in the Legion of Honor.

Mr. Brush was prolific in inventions for many years, some of them being improvements for his arc-lighting system, like the double arc-lamp for all night burning with an automatic cutover from one pair of electrodes to the other; the automatic cutout for each lamp, which operated to by-pass the lamp and avoid disturbing the main circuit in case the carbon electrodes of the lamp became exhausted or some defect in the operating mechanism arose; means for charging storage batteries from the constant-current arc-light system, and so on. Additional inventions were in connection with electroplating, electric storage batteries, the copper plating of carbon electrodes intended for use in arc lamps, various aspects of the construction of dynamos, compound winding of dynamos, and other features pertaining to the field of electrical engineering or collateral thereto. He was naturally a good mechanic and he liked to aid in the work of constructing

experimental machines. One of the earliest examples of Brush compounded electrical generators is now deposited by the writer as a loan in the Ford historical museum at Dearborn, Michigan. The windings of this small machine are reputed to have been put on it by Brush personally. The boldness and originality of Mr. Brush's inventions in the field are illustrated by the fact that various of his patents covered devices which were much coveted for commercial use by competitors and this resulted in considerable litigation over the validity of the patents. It is said that the definitive patents on the double arc-lamp were so frequently in litigation that they were upheld in sixteen different Court decisions. His adequate (as well as early) recognition of the possibility of making the arc-lamp a desirable illuminant for commercial application, his originality in experiment and invention, his capability as a constructor and a business man quickly gave his arc-lighting system a tremendous vogue, and it developed a wide use at a time when it was substantially without electrical competitors. This justly entitles Brush to his often expressed name of Father of Commercial Arc Lighting.

About 1892 the General Electric Company (which then recently had been formed by consolidation) absorbed the Brush Electric Company and Mr. Brush turned to other fields. He was the founder and first president of the Linde Air Products Company which was established in this country; he was president of the Cleveland Arcade Company; and as one of the first citizens of Cleveland he served his community in many capacities. He was a warden of Trinity Cathedral; a member of the Corporation of Case School of Applied Science; a trustee of Western Reserve University, Adelbert College, University School, Cleveland School of Art, and Lake View Cemetery; and member of the Sinking Fund Commission of Cleveland. He was a member of the Cleveland Chamber of Commerce, of which he was president for the two years, 1909-10, and also was active in the Ohio State Board of Commerce and the Chamber of Commerce of the United States. He was at one time president of the Euclid Avenue National Bank in Cleveland.

His professional interests led him into membership in many societies including the American Society of Mechanical Engineers, the American Chemical Society, the American Institute of Mining and Metallurgical Engineers, The Franklin Institute, the Illuminating Engineering

Society, the Archeological Institute of America, the American Historical Association, the American Association for the Advancement of Science (Fellow), the American Physical Society (Fellow), the American Geographical Society (Fellow), the Royal Society of Arts, the British Association for the Advancement of Science, and the North British Academy of Arts (Fellow). He was a charter member of the American Institute of Electrical Engineers, served on its first Board of Directors and was its Edison Medalist of 1913. He was an Honorary Member of the American Society for Steel Treating. He became a Fellow of this American Academy of Arts and Sciences in 1917.

His achievements in the practical development of electric arc-lighting brought him the Rumford Medal of this Academy in 1899, the Edison Medal of the American Institute of Electrical Engineers in 1913 and the Franklin Medal of the Franklin Institute in 1928. University honors were generously accorded him. Western Reserve University conferred on him the degree of Ph.D. in 1880 and LL.D. in 1900. The University of Michigan gave him an M.S. in 1899 and an Sc.D. in 1912. Kenyon College bestowed an LL.D. in 1903.

A large part of his life was lived in his house on Euclid Avenue in Cleveland, which house was built about 1880. In its basement he maintained a well-equipped laboratory and machine shop. It was here that many experimental machines were constructed and his experiments were later carried out in the field of gravitation which, along with "A Kinetic Theory of Gravitation," are described in a series of papers published in the Proceedings of the American Philosophical Society from 1917 to 1928 in succession to earlier communications to *Nature* and *Science*.

Mr. Brush was married to Mary E. Morris of Cleveland in 1875. She bore him a son and two daughters. On his death in 1929 he also had four living grandchildren. On Sunday nights such members of his family as were available dined with him in happy informality and personal intimacy. It was on these occasions that, with his active mind and his intimate association with his children and grandchildren, Mr. Brush seemed to throw off his years and live as one of the younger generation. His wife died many years ago. His son, Charles F. Brush, Jr., was a young man of vigor and intellect who gave promise of large achievements. The tragedy of his death in 1927 was a heavy

blow to the father with whom the young man was on terms of fine intimacy. Mr. Brush established the Charles F. Brush Foundation for the Betterment of the Human Race to which he gave a capital of \$500,000 placed in trust to the memory of his son. Several pamphlet publications of interest have come from this Foundation.

Mr. Brush was stricken with pneumonia in his eightieth year and died at his home in Cleveland on June 15, 1929. He has left to us the memory of a distinguished name for pioneer investigation and invention in the field of applied electricity of which the influences still strongly persist; and to Cleveland the memory of a citizen who lived a life of long-continued service to the community after having (through his bold originality) established a new and important industry within the city.

DUGALD C. JACKSON.

JOHN MASON CLARKE (1857-1925).

Fellow in Class II, Section 1, 1915.

John Mason Clarke, was born at Canandaigua, New York, on April 15, 1857, and died at Albany, New York, May 29, 1925.

He received his early education at the Canandaigua Academy, in which his father, Noah Turner Clarke, was for fifty years a teacher and for almost thirty years the principal.

He graduated from Amherst College in 1877, returning thence to Canandaigua, where he taught in the academy for a year, during which he began work on a detailed survey of the geology of the locality. The next year he was called to Amherst as a temporary assistant to Professor B. K. Emerson, to arrange large collections of minerals and shells in the Appleton Cabinet. In 1880 he taught science at the Utica Free Academy, a position in which two distinguished geologists, James D. Dana and G. H. Williams, had preceded him. Professor Emerson succeeded in having Clarke appointed Instructor in Geology, Mineralogy, and Zoölogy at Smith in 1881. Emerson had studied in Germany and it is probable that it was his example that led his protégé to obtain a leave of absence from this position and repair to Göttingen for study with von Koenen. He remained a little over a year, returning in the fall of 1884. He spent the next academic year teaching Geology, Zoology, and German at the Massachusetts

Agricultural College. In the spring of 1885 he returned to Canandaigua to resume the study of the local geology, add to his collection of fossils, and await a more satisfactory opening. This came, and he entered upon his real life work on January 1, 1886, when he became assistant to James Hall, New York State Geologist and Palaeontologist. Twelve years later, after Hall's death, he became State Palaeontologist, and in 1904, State Geologist and Palaeontologist, Director of the State Museum, and Director of Science in the New York State Education Department. All of these offices, as well as that of Professor of Geology and Mineralogy in the Rensselaer Polytechnic Institute at Troy, which he had assumed in 1894, he held until his death.

Clarke was predestined to be a palaeontologist. His home was surrounded with fossils which were the playthings of his childhood and the absorbing interest of his youth. His father had collected fossils for years, and early supplied books on geology to that one of his five children who showed an interest in this branch of natural science. He probably had very little formal training in palaeontology until his year with von Koenen at Göttingen, but, like most of the palaeontologists of his generation, learned from the fossils and the rocks rather than from books and teachers.

At Albany, however, he was plunged into very practical palaeontological work. At the time he joined the staff, James Hall was 75 years old, and was glad to transfer to younger men the task of actually describing the various species of fossils which occupied the pages of the later volumes of the monumental *Palaeontology of New York*. Volume VII, Crustacea, although published only two years after Clarke's arrival, was almost entirely his work, not only in execution but in plan. Although his first important publication, it shows no evidence of immaturity, and as Schuchert has said, Clarke does not appear to have gone through an apprenticeship, but to have suddenly come forth as a successful descriptive palaeontologist.

Volume VII finished, work was begun on the final volume of the series which appeared in two parts in 1892 and 1894. On the "Introduction to the study of the Genera of Palaeozoic Brachiopoda" Clarke had the assistance of Charles Schuchert for two and a half years, but the writing was done almost entirely by Clarke, under the supervision of Hall. So great a share did he have in the work that Hall deviated so far from his usual custom as to allow the words

"assisted by John M. Clarke" to appear below his own name on the title page, in only slightly smaller type. These volumes, with the "Handbook" which accompanied them, still remain the outstanding works on the morphology of Paleozoic Brachiopoda, and mark, at least in the writer's opinion, the highest point reached by Clarke as a palaeontologist.

Clarke's next important work, and the last as assistant to Hall, was the memoir on the Palaeozoic glass-sponges, issued in 1898, the year of Hall's death.

The period from 1898 to 1904 was for Clarke one of transition. His bibliography shows that he was exceedingly busy during this time on a variety of subjects. His attention was directed largely to the stratigraphic side of palaeontology. As a result there appeared in 1898 and 1904 his studies on the Naples Fauna in Western New York, a work of the utmost importance, treated in a masterly manner.

The Middle Upper Devonian strata had been thought to be nearly barren of organic remains, but Clarke not only found them, but showed their relationships to those of faunas of the same age in Europe. He also explained the stratigraphy of the beds containing them, especially as related to the unlike strata in the eastern part of the State.

The rearrangement which took place in Albany in 1904 brought Clarke for the first time into a position where he had freedom of action. As Director of Science in the New York State Education Department, he was in charge, not only of the State Geological Survey, but also of the State Museum and its several Departments. Highly successful as an executive, he brought the New York State Museum out of its stuffy, dismal old quarters, assembling on the upper floor of the Education Building one of the best museums in the country. Even the invertebrate fossils, usually the despair of the curator of a collection, yielded to his genius, and became an attractive as well as instructive part of the exhibit.

His efforts at public instruction were not confined to the Museum, however, for, realizing the importance of preserving localities of great geological interest, he succeeded in obtaining for the people no less than six reservations now under the administration of the New York State Museum, in themselves virtually out-of-door museums. Nor should it be forgotten that Clarke was very largely influential in the preservation of the scenic beauties of Niagara Falls.

A true palaeontologist, Clarke spent his vacations in the study of palaeontology as a relief from his regular work with fossils. But from the summer of 1900 onward, he shifted the scene of his vacation labors from New York to the peninsula of Gaspé, a land which fascinated him, as it does every lover of the beautiful and the ancient. Many results in the line of history, of folk lore, of old ceramics, of bird sanctuaries, and of fossils came from his wanderings among the cliffed mountains and spurred shores of that still too-little visited land. Two books, "The Heart of Gaspé" (1913), and "L'Île Percée" (1923), interest the general reader, whereas the two memoirs of the New York State Museum, published in 1908 and 1909, descriptive of the geology and palaeontology of Gaspé and adjacent regions, evoked the admiration of his colleagues and brought him the Spindiaroff prize at the International Geological Congress of 1910.

Clarke was also interested in the Devonian of South America. Although he never visited that continent, he contributed far more than anyone else to present knowledge of its Devonian, particularly that of Brazil and the Falkland Islands. His volume, "Fosseis Devonianos do Paraná," (1913), summarizes the greater part of the work which has been done on the subject in South America. This was the last of Clarke's large undertakings in purely descriptive palaeontology.

The fruits of his pondering on history, philosophy, and fossils are included in his address as President of the Palaeontological Society of America in 1911 and of the Geological Society in 1916, his book "Organic Dependence and Disease" (1921), and a paper read before the American Philosophical Society in 1922. Although Clarke would have it appear that his philosophy was derived from his studies of fossils, it must be obvious to anyone who reads these works that the fossils really serve largely as the text which a man of wide human experience, knowledge of the world and of history, chooses as a basis in expounding his views of life. He stood stoutly for individualism and for the ultimately beneficial racial results of the struggle for existence.

To these later years belongs also Clarke's greatest achievement, his "James Hall, of Albany, geologist and paleontologist, 1811-1898" (1921).

Clarke will probably be remembered chiefly for his systematic

descriptions of fossils. He was in no sense a "species maker," although he is credited by Schuchert with being the author of 135 new genera and about 870 species.

John M. Clarke had a charming personality and was the center of the group and conversation wherever he found himself. Of medium height, always slim and distinguished-looking, immaculately dressed, he showed distinct aristocratic tendencies in his person which were also evidenced in his actions and writings. It was not at all an objectionable quality, but one which evoked admiration and respect.

A ready and delightful speaker, Clarke was always in demand at dinners. His graceful manner, witty talk, great fund of knowledge, and personal experiences in many lines made him a delightful companion anywhere. To this personality he owed his great success as administrator of the many offices of the Director of Science in the New York State Education Department.

A very full bibliography of Clarke's writings, compiled by his son, Noah T. Clarke, and Miss Clara Mae LeVene, is appended to Schuchert's "Memorial" in the *Bulletin of the Geological Society of America*, 1926, Vol. 37, No. 1, pp. 72.

PERCY E. RAYMOND.

HENRY WALCOTT FARNAM (1853-1933).

Fellow in Class III, Section 3, 1914.

In the death of Henry W. Farnam, on September 5, 1933, Yale and the nation suffered a great loss, in the fields of learning, good works, and good citizenship. For this man had been a loyal supporter of his *Alma Mater*, an inspiring teacher, a discriminating but generous giver, and a whole-hearted participant in official and unofficial labors concerning the public weal. All these good works he did because he was, in the high sense of the word, a good man, who fortunately had the wordly means to make his good will more effective. Wealth was, to him, not an escape from the day's work, but a release of his great working powers for the more concentrated and effective service of humanity. His father, Henry Farnam, was President of the Rock Island Railroad, a partner of Joseph E. Sheffield, founder of the Sheffield Scientific School of Yale. The son accepted life as a trust; and, though intense in his adherence for all truth, was tolerant, humorous, wise, and human.

Professor Farnam was born November 6, 1853. He studied in Germany and graduated from Hopkins Grammar School before entering Yale. He graduated from Yale in 1874 after taking many honors, both scholarly and social. He continued his studies at Yale—in Economics and Roman Law—receiving, in 1876, his M.A. degree. Then he went once more to Germany, pursuing his studies in the Universities of Berlin, Goettingen and Strassburg. From Strassburg, in 1878, he received the degree of R.P.D. *magna cum laude*. He returned to Yale as a teacher, serving first as a tutor in Latin, later as a Professor of Economics. He served also in the Graduate School and as a member of the governing board of the Sheffield Scientific School. He became Professor Emeritus in 1918, and five years later Yale bestowed on him the degree of LL.D.

He took over the old *New Englander and Yale Review*, subsidizing it and changing its name to *Yale Review*. He made it largely an economic journal until the American Economic Association set up its *American Economic Review*, after which the *Yale Review* became a general magazine.

From 1910 to 1911 he was President of the American Economic Association.

In 1890 he was married to Elizabeth Upham Kingsley, whose sympathetic understanding and cooperation was a continued source of strength and happiness.

His activities were as wide and as varied¹ as his nature was deep and versatile. He favored the League of Nations. He devoted himself to civil service reform, both state and national. He founded the American Association for Labor Legislation and promoted the enactment of a number of laws in the interest of labor. One of these was the national law which ended the "phossy jaw" disease in this country by taxing out of existence the offending industry. He formed and subsidized a committee for the study of tobacco as a fire hazard and in its relation to personal health and economic welfare. He was also a member of the Committee of Fifty, and in that capacity edited its volume on *Economic Aspects of the Liquor Problem*. He early became interested in the first social settlement in New Haven, known as "Lowell House," and gave it both its New Haven and vacation houses. He belonged to a chapter of the National Aeronautical Society, was

¹ Amer. Econ. Rev. 24, 175-177 (March, 1934).

chairman of the State Commission of Sculpture, was a member of the Elizabethan Club of Yale, and wrote a memoir of his father Henry Farnam (1889) and an entertaining book on "Shakespeare's Economics" in 1931.

In the field of strict scholarship, besides numerous articles in American and German publications, he wrote (among other works) "Die innere Französische Gewerbepolitik von Colbert bis Turgot" (1878), "Die Amerikanischen Gewerkvereine" (1879), Chapters on "Government Insurance and Workingmen's Insurance in Germany," in *Yale Readings in Insurance* (1909); and *The Economic Utilization of History* (1913). He edited seven volumes of *Contributions to American Economic History*, the last of which was published in 1933, and he had completed many years before his death the preliminary research and some of the final copy of his own contribution to the series: *A History of Social Legislation in the United States*. This was in connection with the Carnegie Institution of Washington and with the board of Research Associates in American Economic History. For his editorial work he received a medal from the National Institute of Social Science in 1920.

IRVING FISHER.

JOHN RIPLEY FREEMAN (1855-1932).

Fellow in Class I, Section 4, 1913.

In the death of John R. Freeman on October 6, 1932, the Academy lost one of its outstanding members and the engineering profession one of its great leaders. Born on a farm in Maine in 1855, educated in Maine and Massachusetts, and living for the greater portion of his life in Massachusetts or Rhode Island, he was by birth and training a true representative of New England and showed throughout his long life those qualities which many of us believe are particularly representative of New England leaders; integrity, vision, thoroughness, mental and physical strength, and unrelenting industry.

A full account of Dr. Freeman's activities and writings appears in the "Supplement to John Fritz Medal Book" published by the American Society of Civil Engineers in 1934, hence the writer will confine himself to giving in this memoir only a brief outline of his life.

While a student in the Civil Engineering course at the Massa-

chusetts Institute of Technology, young Freeman spent some of his summer vacations working in hydraulic engineering with the Essex Company at Lawrence, Massachusetts; where, through contacts with those early leaders of hydraulic engineering, Mills and Francis, he acquired an enthusiasm for hydraulic engineering and research which persisted throughout his life. In this field he first attained distinction by his paper entitled "Experiments Relating to the Hydraulics of Fire Streams" published in 1889, for which he was awarded the Norman Gold Medal of the American Society of Civil Engineers. In 1900 he reported to the Comptroller of the City of New York the results of an exhaustive investigation of additional water supplies for the City which led to the development of the Catskill Water Supply, and from 1905 to the date of his death he served as Consulting Engineer to the New York Board of Water Supply. Many other communities sought his advice on water supply problems, among which may be mentioned San Francisco, Los Angeles, and the City of Mexico. He was also engaged from time to time by important private companies to advise upon water power developments. Of particular interest to Bostonians was his investigation of the feasibility of damming the Charles River, upon which was based the legislative act authorizing the construction of the Charles River Basin.

His engineering accomplishments early attracted the attention of educational institutions. In 1891 and again in 1892 he was offered by President Eliot the professorship of Civil Engineering in Harvard University, which he declined—considering himself better adapted for business life.

On the retirement, in 1907, of Dr. Henry S. Pritchett from the position of President of the Massachusetts Institute of Technology, Mr. Freeman was asked by President Pritchett, with the approval of the Executive Committee of the Institute corporation, if he would consider becoming his successor. This honor he declined. However, he served the Institute of Technology as a member of the Corporation from October 1893, to the date of his death.

Other educational institutions recognized his attainments by granting him honorary degrees, of which he received five from American and foreign universities.

Dr. Freeman's interest in hydraulic research led to his presentation in 1924 of \$25,000 each to the American Society of Civil Engineers,

American Society of Mechanical Engineers, and the Boston Society of Civil Engineers, the income to be used for the aid of young engineers, particularly those engaged in research work. In addition to the gift of these funds, he assisted financially several students studying hydraulics abroad under college scholarships. He made numerous trips to Europe in order to keep himself informed of what was being done there and to confer with and assist the holders of the Freeman Scholarships.

He also inspired and edited the massive volume published by the American Society of Civil Engineers in 1929 entitled "Hydraulic Laboratory Practice," and it was largely due to his efforts that the National Hydraulic Laboratory was constructed in Washington.

Dr. Freeman's accomplishments in the engineering field would have been enough to suffice most men, but, with his unbounded energy and physical and mental strength, he was able to make a reputation in another field—that of Fire Insurance. In 1886 he became engineer and special inspector for the Associated Factory Mutual Fire Insurance Companies at Boston and remained with these companies for ten years when he resigned to become President and Treasurer of a similar group of Mutual Fire Insurance Companies with offices in Providence, Rhode Island, which position he held until the day of his death. During his administration the insurance in the companies under his management increased more than forty fold. He kept his interests in fire insurance and engineering apart, and many of his engineering acquaintances had no knowledge of his prominence in the field of fire insurance.

One of the last of his major activities was the production of a comprehensive treatise entitled "Earthquake Damage and Earthquake Insurance," consisting of a study of rational bases of earthquake insurance and data for earthquake resisting construction. In connection with his activities in this field he sponsored and financed the visit to this country of the leading Japanese authority on earthquakes—Kyji Suyehiro—who spoke on this subject at a considerable number of American universities and elsewhere.

His successful accomplishments led to honorary membership in engineering societies and at the time of his death he was an honorary member of the American Society of Civil Engineers, the Boston Society of Civil Engineers, the New England Water Works Associa-

tion, and the Providence Engineering Society. Posthumous award of the John Fritz Gold Medal for 1934 was recommended by the Board of Award in October, 1933, and was presented at the Annual Meeting of the American Society of Civil Engineers in January, 1934, his son, John R. Freeman, Jr., receiving the medal on behalf of the family.

Doctor Freeman's active professional life was coincident with the progress of engineering in the United States from a little known and little understood occupation to a profession of outstanding importance in world activities. Perhaps no one man of his era played a greater part than he in bringing about this result, and his life and work will ever serve as an inspiration to other engineers.

CHARLES M. SPOFFORD.

SIR ARCHIBALD GEIKIE (1835-1924).

Foreign Honorary Member in Class II, Section 1, 1900.

Sir Archibald Geikie became the leading British geologist of his time. He was born in Edinburgh, the son of a gentleman of moderate means and cultivated tastes. During four years in the Edinburgh High School, Archibald acquired a strong love for the Latin and Greek classics, and at the same time a great enthusiasm for natural history, especially for geology, stimulated by finding abundant fossils during holiday excursions with his school mates.

In 1850 an old family friend offered him a position in a bank. In preparation for this, he spent two years in the uncongenial atmosphere of a lawyer's office. In the mean time, he made friends among local geologists, and, after studying chemistry and mineralogy under private teachers, in November 1854 he matriculated at the University of Edinburgh, where during one year he excelled in classics and English. But his father having suddenly been called upon to pay a large sum of money, he was obliged to leave the University at the end of the year. Then came the longed for opportunity.

At the age of twenty (1855), he was appointed assistant on the Geological Survey under Sir Roderick Murchison. He did such excellent work in the complicated regions of the Highland schists and on problems relating to glacial geology, that, when a separate branch of the Geological Survey of Great Britain was established for Scotland

in 1867, he was so favorably known that he was made its Director. This position he held until 1881.

When Sir Roderick Murchison founded the chair, he nominated Geikie to be the first Professor of Geology and Mineralogy in the University of Edinburgh, and this position he held with the other from 1871 to the end of 1881. At the beginning of the next year he became Director-General of the Geological Survey of the United Kingdom. From this position he retired in 1901.

He was elected Fellow of the Geological Society of London in 1859 and F.R.S. in 1865.

In 1871 he married Alice Gabrielle Pignatel, whose widowed mother was English and then living in London. They had four children.

For a review of Geikie's achievements as a geologist, the reader is referred to the Proceedings of the Geological Society of London for 1925.¹ Besides numerous contributions in technical journals and reports, he published a number of books, among which may be mentioned his Text-Book of Geology, 1882 (4th edition 1905), and Ancient Volcanoes of Great Britain, 1897.

He visited the United States twice, giving lectures in Boston (1879) and in Baltimore (1897). Those of the latter occasion appeared as "The Founders of Geology," 1897 (2nd edition 1906).

Many honors came to him at the hands of governments, universities, and societies, at home and abroad. He was knighted in 1891 and created K.C.B. in 1907.

During ten years (1903-1913) following his retirement from the Geological Survey, Geikie's chief occupation was the business of the Royal Society, first as General Secretary and later as President. The close of that period was marked by the bestowal upon him of the Order of Merit, an honor especially cherished as coming exclusively from the hands of the King. He retired to a country place he had built in Surrey not far from London and there occupied himself pleasantly in the preparation of an autobiography.² It was finished at almost the close of his life, and is an important contribution to the history of science.

H. W. SHIMER.

¹ Quart. Jour. Geol. Soc. 81, lii-lx.

² "A Long Life's Work," London: Macmillan, 1924.

VICTOR GOLDSCHMIDT (1853–1933).

Foreign Honorary Member in Class II, Section 1, 1914.

Professor Victor Goldschmidt, Foreign Honorary Member of the Academy since 1914, died in Salzburg, Austria, on the 8th of May, 1933. He was born in Mainz, Germany, in 1853 and very early in his career entered upon his life work, the formulation and interpretation of the data of mineral crystallography. He began his life-long residence at Heidelberg in 1888, first as docent, later as professor (extraordinary) of crystallography. Possessed of abundant means, he established his own Institute, where all his work was conducted and where he accumulated an unrivalled library of mineralogy and an important collection of crystals which was the basis of a long series of important researches. Students came to him from many lands and carried his new methods of description away with them. And he preserved his close friendship with this ever-widening circle of disciples by untiring correspondence and by visits in person, which took him twice to America and once around the world.

Goldschmidt's enduring monument is the series of works in which he presented his laborious collation of the whole literature of the crystal forms of minerals. The first of these works to be published was the *Index der Krystallformen* published from 1887 to 1891. The introduction to this catalogue of the known crystal forms of all the minerals developed a new system of nomenclature and a new mode of defining the angular relations of the faces of crystals. New instruments for measuring crystals were designed by him and elaborated by his private mechanic; and the two-circle goniometer, which was the direct outgrowth of his ideas, has become the standard instrument of the present day. To meet the needs of the new methods, new tables of angles were necessary and these he calculated with an incredible outlay of energy and published in 1897 as *Krystallographische Winkeltabellen*. Next began the compilation and publication of all published figures of crystals of minerals. This *Atlas der Krystallformen*, in nine quarto volumes of plates with accompanying volumes of explanatory notes, appeared from 1912 to 1923.

The publication of these various works was never permitted to interrupt the steady stream of papers from Goldschmidt's pen in which he used the materials thus laboriously made available or added new studies which illustrated his methods of calculation.

Growth and solution forms and vicinal planes, "Accessorien" as he called them later, were first brought adequately into the range of goniometric study by the development of his new instruments and were used to illumine the form series of minerals. Many papers were devoted to the discussion of the distribution of forms in zones; these investigations had as a major outcome the formulation of his "Law of Complication" and his theory of Harmony. In the latter a number law derived from crystals is extended to the discussion of serial arrangements as widely diverse as color scales, musical scales, and the spacing of the planets in the heavens. These philosophical developments of crystallographic studies, which included a new analysis of musical harmony and a theory of the development in man of the color sense, increasingly occupied his interest during his later years. But Goldschmidt's devotion to crystal morphology remained dominant and at the time of his death he was enthusiastically entering a new field of study, seeking to apply to the points of the interference figure of Laue X-ray photographs the law of complication derived from the study of crystal faces.

In 1916 Professor Goldschmidt and his wife established and endowed the "Josefine und Eduard von Portheim-Stiftung für Wissenschaft und Kunst" as an adjunct to the University of Heidelberg. One branch of this foundation is the "Victor Goldschmidt Institut für Kristallforschung," an institute which will inherit his library and collections and insure the continuation of his monumental work through the years to come. It is allied to, but independent of, the University.

In 1928 in celebration of his seventy-fifth birthday a handsome *Festschrift* was presented to Goldschmidt by his students. The introduction by Dr. Milch, Goldschmidt's first student, gives an admirable picture of his life and work. Appended is a complete list of his publications numbering 177 up to that time.

Goldschmidt has left to the students of crystal morphology an inexhaustible mine of material to be drawn upon by later workers. New methods which he introduced will doubtless be modified: his theories of crystal growth may be outmoded: but his work ended an era. And future progress in the description of crystals will necessarily be founded upon his monumental works.

CHARLES PALACHE.

FRITZ HABER¹ (1868–1934).

Foreign Honorary Member in Class I, Section 3, 1914.

Fritz Haber was, without doubt, the most versatile, and, many will agree, the leading chemist of his generation. The demands of modern science force a leader of thought into high specialization. Haber rose above this tendency. His preparation for work in chemistry was attained by attendance at the Universities of Heidelberg, Berlin, Jena, and Zurich and at Karlsruhe, and he had his interest aroused in many fields of chemistry by the men under whom he studied. Upon the completion of his training he entered the chemical industry and there gained a point of view that was an important factor in his subsequent work. He stood preëminent in the application of pure science in the solution of industrial problems of world significance. His synthesis of ammonia from the hydrogen contained in water and the nitrogen of the air, which he developed through large scale production, was the basis upon which he was awarded the Nobel prize in 1918. This great contribution to industrial chemistry came at a most opportune time for Germany. As it is possible to convert ammonia into nitric acid, which is used in making explosives, Germany was in a position to wage war without reliance upon the well nigh impossible importation of a chemical necessary in the manufacture of munitions. Haber's success led immediately to research throughout the world in allied fields in which reactions were studied under the influence of catalysts and high pressures. His work has led to most important developments in industrial chemistry.

Haber's versatility was shown by contributions of a fundamental nature in physical, electro, organic, inorganic, analytical, and biochemistry. He showed himself to be a pioneer by his books, published when a young man, on "Thermodynamics of Technical Gas Reactions" (1905) and on "Technical Electrochemistry" (1898). He was one of the earliest workers in the field of electron emission from heated metals.

It was the good fortune of the writer to spend a year in Haber's laboratory (1910–1911) when he was completing his work on ammonia

¹ References: Brief biography with portrait in "Die Nobelpreisträger" by Victor Junk; Address by Paul Askenasy on Haber's sixtieth birthday, *Zt. für angewandte Chemie*, **41**, 1289 (1928); Address by W. Schlenk before the German Chemical Society, *Ber. d. deutsch Chem. Ges.*, **67**, A 20 (March 1934).

and opening up new lines of work. He was also busy in organizing, building, and equipping the laboratory of physical chemistry of the Kaiser Wilhelm Institute, of which he had been appointed the first Director. Haber was a good lecturer, had an agreeable personality, and was pleasingly informal with his students. He was a rapid thinker, was sure of his opinions, and was ever ready to combat others who did not agree with him.

Fritz Haber was born December 6, 1868. In 1894 he was appointed an assistant at the Technische Hochschule at Karlsruhe, in 1898 *ausserordentlicher* Professor and in 1906 Professor and Director of the Physico-chemical Institute. During the World War he was the technical head of the chemical warfare service of Germany. Subsequently he made for his government a world survey of the gold content of sea water, in which he developed new analytical methods of great refinement for the quantitative determination of the metal. He died January 29, 1934.

JAMES F. NORRIS.

ELIJAH CLARENCE HILLS (1867-1932).

Fellow in Class IV, Section 3, 1918.

Elijah Clarence Hills was born at Arlington, Illinois, on July 2, 1867. His early training was received in part in North Carolina. He graduated with the degree of A.B. from Cornell University in 1892, and then spent a year there as a fellow in Romance languages. During 1893-1894 he studied Romance philology at the University of Paris. In 1906 he was awarded the degree of Ph.D. by Colorado College and, at the same time, Rollins College bestowed upon him the honorary degree of Litt.D. On June 22, 1890, he married Metta Vergil Strough; to them came four children—Elijah Justin, George Strough, Clarence Ballard, and Ruth.

Not long after his sojourn at Paris, Professor Hills joined the staff of Rollins College in Florida, and remained there as professor of modern languages from 1896 to 1901, acting also as President for a short while. Because of threatened tuberculosis he moved to Colorado Springs, and at Colorado College he was professor of Romance languages from 1902 to 1918. During 1916 to 1918 he was on leave of absence from his post at Colorado College; for the first part of this

period he was Librarian of the Hispanic Society of America in New York City, and in the latter part he performed editorial work in the New York offices of the publishing firm of D. C. Heath and Company. He received a call in 1918 to the University of Indiana where he became professor of Romance languages and head of the Romance department; after fulfilling the duties of this office for four years, he passed to the University of California and there he was professor of Spanish from 1922 to 1924, and professor of Romance philology from 1924 to his death on April 21, 1932.

During the summer of 1900, Professor Hills was one of the Spanish-speaking instructors appointed by President Eliot and the Fellows of Harvard College to instruct the two thousand teachers brought from Cuba to Cambridge; in 1911-1912 he was again at Harvard as the exchange professor from Western institutions.

Professor Hills was a member of many organizations occupied with the teaching of modern foreign languages. Among his most notable distinctions were these: he was a Fellow of the American Academy of Arts and Sciences, elected in 1918, a member of the Hispanic Society of America, a member of the Société de linguistique of Paris, and a Corresponding Member of the Spanish Academy. The Spanish government made him a Knight-Commander of the Order of Isabella.

Professor Hills's publications relate chiefly to the languages and literatures of the Hispanic peninsula and of Hispanic America, and to modern French and its literature. In collaboration with Professor J. D. M. Ford he issued a *Spanish Grammar* (1904), a *First Spanish Course* (1917), a *Portuguese Grammar* (1925), and a *Spanish Grammar for Colleges* (1928). Of these books about a million copies have been sold. His other works embrace numerous annotated Spanish and French texts and a variety of learned articles on matters of phonological and literary interest.

Fighting for a protracted period against serious ill health, Professor Hills preserved always a serene and courageous attitude. He was a thoroughgoing Romance philologist, searching in his methods of investigation and lucid in his exposition of results. His was a kindly spirit and one that easily won the good will of his colleagues and his students. The world is much the poorer for his departure, and the writer of this notice is deprived of a loved co-worker.

J. D. M. FORD.

WILLIAM HENRY HOLMES (1846-1933).

Fellow in Class IV, Section 4, 1919.

William Henry Holmes, the son of Joseph and Mary Heberling Holmes, was born near Cadiz, Ohio, on December 1, 1846 and died at Royal Oak, Michigan on April 20, 1933. He had little academic training and never received a college degree. Early in life he developed great skill with his pencil. A year in Germany studying art and visiting the European museums served to crystallize this talent. It was owing to his abilities in drawing that he entered the United States Geological Survey in 1872 under F. V. Hayden. He soon became much interested in geology, becoming assistant geologist two years later. The Far West excited his talents and the hundreds of drawings showing exact physiographic features, especially those of the Grand Cañon, have never been equalled. About 1875 the cliff dwellings on the San Juan in Colorado served to fasten his interest on the early works of man in America and this subject became the dominant concern during the remainder of his life. Primitive art was his special province, as shown in several pioneer papers in the early Reports and Bulletins of the Bureau of American Ethnology. In 1882 he became Curator of Aboriginal Ceramics in the United States National Museum and, shortly after, was transferred to the Bureau of American Ethnology of the Smithsonian.

Holmes became the leader of a group who arrayed themselves against the previously generally accepted belief that man lived in the New World contemporaneous with the glacial period. He was the last remaining American archaeologist who believed that Asiatic influences could be found in the development of the Maya civilization. The work for which he is most famous is his "Archaeological Studies among the Ancient Cities of Mexico," a publication of the Field Museum, Chicago, where he served as Head Curator of Anthropology from 1894 to 1897. His relatively short trip to Mexico and Central America resulted in a book which is still most essential for its detailed architectural drawings of ancient buildings. His famous sketches of ruined sites have been more often reproduced than any other single feature connected with Middle American archaeology.

Returning to the Smithsonian in 1897, he was appointed Head Curator of Anthropology in the United States National Museum, and served in this position for over twenty years—interrupted, from

1902 to 1909, when he succeeded Major J. W. Powell as Chief of the Bureau of Ethnology. The National Museum under his guidance became a model of its kind. In 1920, he was elected the Director of the newly established National Gallery of Art.

He was a member of the National Academy, a member and former president of the Washington Academy of Sciences and of the Cosmos Club. His membership also included the National Institute of Fine Arts and the Royal Anthropological Institute of Great Britain. He received the Loubat Prize from Columbia University in 1898. Noted as a mountain climber, he was the first to ascend several high peaks in the Rockies and two mountains have been named for him. On his seventieth birthday his colleagues and friends presented him with a *Festschrift*. His bibliography includes almost two hundred books and papers.¹

He is the last of the group of the pioneers in American archaeology, which include Brinton, Putnam, Cyrus Thomas, and Fewkes.

ALFRED M. TOZZER.

JOHN HORNE (1848-1928).

Foreign Honorary Member in Class II, Section 1, 1925.

On January 1, 1848, John Horne was born at Campsie in Scotland, the land where Hutton and Playfair had laid the foundation of sound, modern geology. Educated at the High School and University of Glasgow, a student under Lord Kelvin, Horne joined the staff of the Geological Survey of Scotland in 1867. From 1901 to 1911 he served as its Director. Throughout his many years of active field work he was completely associated with his colleague, Dr. B. N. Peach. Such a degree of coöperation as that between the brilliantly suggestive, intuitive Peach and the cautious yet open-minded, coolly rational, and thoroughly skilled Horne has seldom been matched in the history of science. The two men were the "Castor and Pollux," the "Investigator Twins," of British geology. The fused products of their labors were related to many phases of their science, but these inseparable men will always be particularly famous for their elucidation of earth structure in the complicated Southern Uplands and the

¹ See "American Anthropologist" (n. s.) Vol. 35, pp. 755-764, 1933.

Northwest Highlands of Scotland. Their memoir on the latter region, where Peach and Horne finally demonstrated the slicing of the earth's crust and the bodily thrusting of thick slice on thick slice, is destined to be a permanent classic in geological science. The two masters began a comprehensive work on Scotland, but only a part of it was completed, this being posthumously published in 1930 under the title "Chapters on the Geology of Scotland." Horne himself died on May 30, 1928, "leaving a great name and a memory that is sweet and fragrant."

From 1915 to 1919 Horne was President of the Royal Society of Edinburgh. He was President of the Geological Section of the British Association for the Advancement of Science; long a responsible Vice-President of the Royal Scottish Geographical Society. He was given honorary doctorates by the universities of Aberdeen, St. Andrews, and Edinburgh, and in 1900 was elected to Fellowship in the Royal Society of London. He was awarded the Neill Medal of the Royal Society of Edinburgh, and the Wollaston Fund, Murchison Medal, and Wollaston Medal of the Geological Society of London. But the record of this genial leader will receive still greater appreciation in the future, as his technical skill and his power of imagination, always under the control of indisputable facts, continue to influence generation after generation of geologists the world over.

REGINALD A. DALY.

FRED DAYTON LAMBERT (1871-1931).

Fellow in Class II, Section 2, 1914.

Professor Fred Dayton Lambert was born at Muscatine, Iowa, October 28, 1871, and received his early training in public schools of that town. A boyish interest in natural history developed early. His father's desire for him to study medicine and his interest in natural history led him in 1891 to matriculate in Tufts College, where he came under the influence of Professor John Sterling Kingsley, one of the leading zoologists of his day.

Kingsley soon recognized young Lambert's bent for biology and his exceptional skill in drawing. As a student assistant in biology Lambert showed much originality and ability. Through Kingsley's influence Lambert's parents were persuaded to let him work for his

doctorate in zoology. Three degrees were acquired at Tufts, Ph.B. in 1894, A.M., Ph.D. in 1897.

Although Lambert's doctor's thesis was based upon the study of the circulatory system of the salamander, most of his research and teaching was done in the field of botany. Through the influence of Professor J. E. Humphrey at Woods Hole, Lambert became interested in algae and became one of the leading algologists in America. Together with Mr. F. S. Collins he made a study of the green algae of North America, which appeared in the series of Tufts College *Studies*.

After his graduation Lambert became an instructor in biology in Tufts for the year 1897-98. The next year he served as sub-master in the Edward Little High School of Auburn, Maine. From 1899 to 1904 he was instructor in natural history in Tufts College, Professor of Biology from 1904 to 1913, and Professor of Botany from 1913 to 1931.

In 1903 he married Mary Anna Ingalls of Auburn, Maine, who survives him. A single child, Elizabeth Allen, was born to them.

The year 1910 was spent by Professor and Mrs. Lambert in Europe, where he studied botany with Oltmanns in Freiburg and spent several months at the Stazione zoologica in Naples.

Professor Lambert was a member of the American Academy of Arts and Sciences, Phi Beta Kappa, American Association for the Advancement of Science, Botanical Society of America, New England Botanical Club (President 1914-17), Boston Society of Natural History.

While he published few scientific papers, these were genuine contributions to our knowledge of the life histories of algae. His chief interest was in his students by whom he was greatly beloved. Rarely a year passed when one or more students were not influenced to take up the study of algae as an avocation. His power of clear exposition was remarkable and he succeeded in infecting many with his zest for knowledge. He was a friendly man with democratic sympathies and with a genius for making friends among all classes of people.

HERBERT V. NEAL.

JAMES ARNOLD LOWELL (1869-1933).

Fellow in Class III, Section 1, 1932.

James A. Lowell was born at Newton on February 5, 1869; educated at Harvard College (A.B. 1891) and Law School (LL.B. 1894). He came of a family long connected with the United States District Court, which had furnished a reporter and two judges to that court. He practiced law (with his father and brother) in Boston for 28 years, being at the same time a member of the state legislature, and a member of several important commissions. In 1922 he was appointed a judge of the District Court, and continued in that position until his death on November 30, 1933.

As a judge, Lowell thought for himself and was not afraid to decide a case as his own idea of the law led him. He was the first to hold good a marriage by proxy, good where made; and his opinion is the leading opinion on the subject. He refused to give up on interstate rendition an accused negro to Virginia, on the ground that he would be denied a fair trial; and although he was severely criticised and an attempt was made in Congress to impeach him, and although his judgment was reversed in the Circuit Court of Appeals, his decision remains an example of his courage, his originality of mind, and his thinking for himself.

J. H. BEALE.

RICHARD COCKBURN MACLAURIN (1870-1920).

Fellow in Class I, Section 2, 1911.

Richard Cockburn Maclaurin was born in Lindean, Scotland, June 5, 1870. He came of distinguished ancestry, being directly related to Colin Maclaurin, the famous mathematician of the early eighteenth century. His father, a minister of the Scotch Presbyterian Church, moved with his family to New Zealand when Richard was five years old and it was there that he received his early education. It was assumed by his father, who was his first teacher, that he was to become a teacher of mathematics, for which science he showed great ability at an early age. When thirteen years old he went to Auckland to prepare for University College. There he made his B.A. and M.A. degrees with distinction, but having won competitive

scholarships in two colleges at Cambridge, England, he completed his education in England. He entered St. John's College, Cambridge, in 1892 where he made an extraordinarily brilliant record. He was not only first in the mathematical tripos of 1896, but the following year was awarded the coveted Smith Prize in Mathematics, the significance of which may be appreciated when it is recalled that previous recipients included such names as Sir John Herschel, Sir George Stokes, Lord Kelvin, Lord Rayleigh, James Clerk Maxwell, Sir George Darwin, Sir Joseph Larmor, Sir J. J. Thomson. He was honored by being elected a Fellow of St. John's College.

The following year he also won the Yorke Prize—the highest award in the field of Law—for a thesis on “The Title to Reality.” This very unusual achievement was commented upon by the Cambridge University Review as follows:

“This Yorke Prize Essay is in many respects a notable work. It is conferred on Mr. Maclaurin who has distinguished himself in a way that is, we believe, unique in the modern history of the University. He has gained the two most coveted university prizes that are awarded for originality in two completely distinct branches of learning—Mathematics and Law.”

In 1898 Dr. Maclaurin was offered the chair of Mathematics at Victoria College, Wellington, and returned to New Zealand. There he began important researches in Mathematical Physics, particularly in the field of Physical Optics, which he published in a treatise entitled “Theory of Light.” In recognition of the importance of this work, the University of Cambridge conferred upon him the degree of Doctor of Science in 1908. He also devoted much attention to the educational problems connected with the University and was instrumental in establishing the Law School, of which he was Dean from 1905 to 1907.

When, in 1905, Columbia University sought to fill the chair of Mathematical Physics, a world-wide survey of leading physicists resulted in the choice of Dr. Maclaurin for the position. He accepted the call to Columbia in 1907 and with his family took up his residence in New York. His wide interests and remarkable abilities, not only as a scientist but also as an educator, were at once recognized, and it did not take long to convince the Corporation of the Massachusetts Institute of Technology that in him were combined

those qualities for which they had been seeking for several years in a new President. Dr. Maclaurin was offered the Presidency of the Massachusetts Institute of Technology in November 1908 and was inaugurated on June 7, 1909. His presidency was one of the most brilliant in the history of the school. It was due to his vision and untiring efforts that he was able to raise funds, not only for rebuilding the Institute on its present site in Cambridge, but for its endowment. Technology moved to Cambridge and the new buildings were dedicated in June 1916. When, the next year, the United States entered the war, Dr. Maclaurin was appointed Educational Director of the Student Army Training Corps under the War Plans Division of the General Staff and devoted himself untiringly to this work until its close. The facilities offered by the Institute's new plant and equipment for the training of officers and for research connected with the national defense were at once organized by him and placed at the service of the government.

In January 1920 Dr. Maclaurin was to announce at a Jubilee Banquet of the Technology Alumni the name of the Institute's great benefactor, Mr. George Eastman. It was not possible, however, for him to attend the dinner owing to an attack of pneumonia, from which, in a weakened condition due to overwork, he was unable to recover. He died, January 15, 1920, just as he saw his ambitions for Technology realized.

The love and esteem with which Dr. Maclaurin was held by his colleagues could not be better expressed than by the tribute written at the time of his death by Professor William T. Sedgwick, senior member of the Faculty:

"Dr. Maclaurin's life and work will be for us ever a shining example pointing towards the lofty heights of his ideals. His was a world career. No narrow limitations of his native Scotland hedged him in. New Zealand beckoned him and he went. America called him and he came. As a great man of science he studied deeply, planned carefully, acted boldly. As a worker he was indefatigable; as a student modest and profound; as a friend faithful unto death; as a leader we shall not look upon his like again."

It is well said that his monument is the new Technology on the banks of the Charles.

Dr. Maclaurin was the recipient of many honorary degrees: Uni-

versity of Cambridge, LL.D. 1904; University of Cambridge, Sc.D. 1908; Dartmouth College, Sc.D. 1909; Wesleyan University, LL.D. 1909; Harvard University, LL.D. 1910; Denison University, LL.D. 1914.

His membership in numerous academies and scientific societies is recorded in "American Men of Science."

In 1904 Dr. Maclaurin married Miss Alice Young of Auckland, New Zealand. Mrs. Maclaurin and two sons, William Rupert Maclaurin and Colin Maclaurin, survive him.

H. M. GOODWIN.

JOEL HASTINGS METCALF (1866-1925).

Fellow in Class I, Section 1, 1911.

The mind of a theologian frequently turns to the stars for diversion. Thus it was with Joel H. Metcalf. Born in Meadville, Pennsylvania on January 4, 1866, he was a minister of the Unitarian Church from 1891 to the time of his death in 1925. His religious training was obtained from the Meadville Theological School, supplemented by advanced study at the Harvard Divinity School and at Allegheny College where in 1892 he received the Ph.D. degree. The honorary degree, Doctor of Divinity, was conferred upon him in 1920 by the Meadville Theological School.

Throughout his very busy life as a minister, astronomy was his avocation. The stars had from boyhood exercised a great fascination upon him. When but twelve years of age he fed his fancy upon astronomical books from the Sunday School library, such as Proctor's "Other Worlds than Ours," and with interest quickened by the solar eclipse of 1878, he commenced star-gazing with an abandoned lens which he picked up and mounted.

In the early days of his ministry, when at Burlington, Vermont, he bought a second-hand photographic telescope, but there is no record of definite work before 1903 when he went to Oxford University. He had been advised to take a year's rest. Rest meant to him a change of activity, as evidenced by his strenuous courses in theological subjects at Manchester College, and also by his participation in astronomical work at the University Observatory under Professor Turner's leadership. The Oxford Zone of the Astrographic Chart,

the Great Star Map, was being carried on, and the young American preacher was initiated into the art of taking and measuring photographic plates. In March 1904, he published in the *Monthly Notices of the Royal Astronomical Society* a paper based upon some of his work at the Oxford observatory, entitled "Positions and Photographic Magnitudes of Ninety Stars surrounding the Variable, R Cygni."

Returning to America, he was minister for several years at Taunton, Massachusetts, where he established a private observatory fitted with a 10-inch telescope of his own construction. At this time he started surveys for the discovery of minor planets, by his own method of guiding the telescope according to the estimated motion of such an object. The images of stars are accordingly trailed, but an object in the solar system, if present, forms a dot more or less round. By this method, very faint asteroids were photographed and discovered. His first successful photographs led him to call at the Harvard Observatory, saying that he had something in which he thought the Director, Professor Edward C. Pickering, would be interested. This call was the beginning of a close friendship for life between the two men, which resulted in Dr. Metcalf's benefactions to the Observatory—the grinding of several excellent lenses. He became exceedingly skilful in applied optics, so that for years he had in this country no superior in the making of photographic lenses. He computed the curves and with something like innate genius ground the glass to excellent form. His skill and zeal resulted in the discovery of forty-one minor planets and numerous variables on his photographic plates. He also found six comets visually with a comet-seeker of his own construction. For five of them which were new, he received medals from various societies.

Unprecedented perhaps was his experience in 1919 while sweeping for comets at his camp on an island in Lake Champlain. On the evening of August 20, he found a new comet and soon after he started sweeping the sky on August 22, another new comet "swam into his ken."

From 1910 to 1920, Mr. Metcalf was minister of the Unitarian Society at Winchester, Massachusetts, only a few miles from the Harvard Observatory. Relations resembling that of son and father arose between him and Professor Pickering. When a Winchester

photograph revealed anything of interest it was at once brought to Cambridge for verification.

Many conferences ensued concerning new telescopes. As a result of this friendship, two of the most useful lenses in making the Harvard collection of celestial photographs, the 16-inch doublet and the 10-inch triplet, were ground gratuitously by Dr. Metcalf. No effort was too great for him to make in order to improve the definition, and when images on plates taken with the 16-inch doublet were poor toward the edges of the plates, he said, "I can do no better unless you can give me curved plates." Professor Pickering offered to think over that subject and the result was that curvature of the plates was obtained by pneumatic pressure.

Dr. Metcalf was a member of the Visiting Committee of the Ladd Observatory and for several years was Chairman of the Visiting Committee of the Harvard Observatory. Besides being a Fellow of the American Academy, he was a member of the American Astronomical Society, whose meetings he frequently attended.

During the Great War, he rendered distinguished service. Receiving a leave of absence from the Winchester Church, he went overseas with the American Infantry as Secretary of the Young Men's Christian Association, and shared the dangers and privations of the common soldier. He was cited for special courage at Chateau-Thierry. Later he took an active part in the reconstruction of Roumania, visiting many parts of the country with considerable risk to life and health.

On his return to this country, he became minister of the First Parish, Portland, Maine, which he held until his death on February 21, 1925. He was survived by his wife and two children, Mrs. Eldredge F. Stoneham and Herbert E. Metcalf.

He died suddenly in the midst of his many church duties and activities. He was also engaged upon making the largest lens known of the triplet form, a 13-inch, which is now in active use at the Lowell Observatory. It has already become a famous telescope because on a photographic plate taken with it in 1930 the faint and distant major planet, Pluto, was discovered.

Dr. Metcalf's scientific activities never dulled his interest in humanity. Always genial, enthusiastic, and energetic, it has been said that his ministry appealed especially to men in all walks of life.

His enthusiasm extended to all forms of human endeavor, and he seemed to be equally at home whether personally conducting parties through Europe, or sweeping for comets on the quiet island.

Generously tolerant to all creeds, charitable to all sorts of people, his own faith stood fast and undisturbed through the many vicissitudes of life.

ANNIE J. CANNON.

EDWARD FURBER MILLER (1866-1933).

Fellow in Class I, Section 4, 1914.

Edward Furber Miller was born January 18, 1866 in Somerville, Mass., the son of William Gibbs and Sarah Furber Miller.

After his early education in the public schools of Cambridge, he entered the Massachusetts Institute of Technology and received the degree of Bachelor of Science in Mechanical Engineering in 1886. In 1921 he was awarded the honorary degree of Doctor of Science by the Rhode Island State College.

Following his graduation from the Institute of Technology he was appointed a member of its instructing staff. In 1892 he became Professor of Steam Engineering; and, on the retirement of Professor Gaetano Lanza in 1911, he was placed in charge of the Department of Mechanical Engineering, which position he held until his death, June 12, 1933, at his home in Newton Center.

Besides carrying his regular work at the Institute during the war, he had charge, by appointment of the Shipping Board of the United States, of the establishment and direction of training schools located in various parts of the country for preparing men for service as engineer officers of the U. S. Merchant Marine. At the close of the war, he was instrumental in the forming of arrangements with the Army and Navy Departments of the U. S. Government for the establishment of special courses at the Institute for Officers of the Army and Navy. He was commissioned a Colonel in the Ordnance Reserve, and in 1921 he was appointed Dean of Army Officers by the Corporation of the Institute.

Following the death of President Maclaurin of the Institute of Technology, he was appointed one of three Faculty members to serve as an Administrative Committee of Institute Affairs until the election of President Stratton in 1923.

He was active in many professional societies. He was a member of the American Society of Mechanical Engineers, the American Society of Civil Engineers, the Boston Society of Civil Engineers, the American Society of Refrigeration Engineering, the National Association of Stationary Engineers, a life member of the Massachusetts Charitable Mechanics Association, and other engineering organizations. He was an authority on the design and operation of steam power plants, and as such served for many years as a member of the Boiler Code Committee and the Power Test Code Committee of the American Society of Mechanical Engineers. His advice as an expert was widely sought by industrial concerns. For many years he served the State of Massachusetts and the cities of Boston and Cambridge on various Boards and Committees.

He was responsible for the design and development of the laboratories of the Department of Mechanical Engineering from very modest beginnings at the old site of the Institute in Boston to the extensive equipment of ten or more laboratory divisions of the Department in the present buildings in Cambridge.

Notwithstanding his heavy administrative duties he continued the teaching of students, in which he was always actively interested. As an expert in his field, he brought into the classroom a fund of knowledge gained from practical experience, by which he was able to give to the students a more thorough and vivid appreciation of what the Mechanical Engineer is called upon to face in the practice of his profession than could be accomplished through the study of books alone.

It may be said that no man in his profession was regarded by his former students with a higher degree of respect and gratitude and affection than was he.

CHARLES F. PARK.

ELIAKIM HASTINGS MOORE (1862-1932).

Fellow in Class I, Section 1, 1901.

Eliakim Hastings Moore was born at Marietta, Ohio, on January 26, 1862. He came of a distinguished family, his father being Bishop David Hastings Moore of the Methodist Episcopal Church. At the age of thirty he was already internationally known as algebraist, group

theorist, geometer, and analyst of high rank, and was called to be professor and head of the department of mathematics at the newly founded University of Chicago. He remained at Chicago in that position until his death on December 30, 1932.¹

During the last twenty-five years of his life, his mathematical interests were in the field which he called General Analysis. While his published work during this period was not extensive, there can be no question that the number of his creative ideas was large. These ideas were shared freely by him with his students and colleagues; but a desire for perfect formulation by means of a definitive symbolism interfered with publication. His General Analysis foreshadowed a good deal of European mathematics which has arisen since, although it is not likely that Moore will receive full credit for what he did. He himself felt in his later years that publication of his results did not interest him greatly.

Moore will always be remembered by the many who knew him as lovable and inspiring to an extraordinary degree. He appreciated deeply the beauty of mathematics and communicated this appreciation to others. Among his many students have been a number of the most important American mathematicians. This has been due in a large measure to the enthusiasm which he inspired in his students and to his generous interest in their scientific development.

The same quality of sensitiveness and desire for perfection that made it difficult for him to publish his work in the latter part of his life showed itself in all of his personal relations. He was utterly lacking in any selfish interest and sought ardently for the ideal in so far as he could achieve it.

When the astonishing history of the development of American mathematics during the past forty years is written, Moore will certainly take a very high place in it as a great and beloved leader.

GEORGE D. BIRKHOFF.

¹ His colleague, Professor G. A. Bliss, of the University of Chicago has published two biographical notes, to which the reader is referred for a detailed account:

Eliakim Hastings Moore, Bulletin of the American Mathematical Society, Vol. 39, 1933.

Scientific Work of Eliakim Hastings Moore, *ibid.*, Vol. 40, 1934.

EVERETT MORSS (1865-1933).

Associate, 1925; Fellow in Class III, Section 4, 1932.

Everett Morss died on the 27th December, 1933. The son of Charles Anthony and Mary Elizabeth Wells Morss, he was born in Boston the 6th of March, 1865. He was graduated from the English High School in 1881 and from the Massachusetts Institute of Technology with the degree of Bachelor of Science in Mining Engineering in 1885. In 1923 the honorary degree of Master of Arts was conferred on him by Tufts College.

Boston, in which he was born and educated, and its immediate vicinity continued to be for his whole career the centre of his many activities and happy family life. Immediately after his graduation at Technology he entered his father's business, The Morss & Whyte Company, which at that time was developing black weatherproof wire, a new type of insulated wire for use by electric light companies. In 1895 The Simplex Electrical Company, now Simplex Wire & Cable Company, was incorporated to carry on and further develop the insulated wire business, which by this time had become primarily the manufacture of rubber covered wire. He was Vice-President of the new company from its inception and, following his father's death in 1903, became President, an office which he held at his death. Although he received very able assistance from his brothers and others in the company, his was the guiding spirit. He felt that the developing of the business depended on two main factors: first, the highest possible quality for the standard products of the company, which he attained and developed through painstaking research; and skilful control of factory processes. He was one of the first manufacturers in New England to employ a rubber chemist and his company has always remained in the forefront of rubber technology. Through his ability along these lines he became a recognized leader in the industry throughout the United States.

Most of his time was spent at the factory until he went to Washington in 1917 as a member of the War Industries Board, although he continued always an important factor in formulating the general policies of the company.

After his return from war service in Washington, he was for some time Fuel Administrator of Boston and gave his time to a more general administration of the affairs of his company, although he

still continued to keep close contact with manufacturing problems and developments. Within himself he combined the skilful and resourceful master of industry with the man of broad sympathies concerning all that touched human welfare and happiness.

With a training and mind which made him singularly informed as to both the industrial and scientific side of the arts generally, he was particularly qualified for fellowship in this society. His unfailing interest in all that promoted education, good citizenship, and the wholesome comradeship of joint efforts for better things caused him to give almost over-generously of his time and energies to the institutions and activities with which he was connected. For twenty-seven years he was associated with the affairs of the Massachusetts Institute of Technology, twenty-four of which he served as a member of the Corporation and twelve as Treasurer, which latter position he held at death. During the construction of the new Technology buildings in Cambridge, during the trying period of the War, and during the critical months following the death of President Maclaurin he bore a heavy load of responsibility with cheerfulness, patience, and soundness of judgment. He was active in the Boston Chamber of Commerce and its President in 1931-32. At his death he was President of the Franklin Foundation and director of The First National Bank of Boston, Old Colony Trust Company, Colombian National Life Insurance Company, Liberty Mutual Insurance Company, Arthur D. Little, Inc., Rumford Chemical Works, and, as has been noted, director and President of the Simplex Wire & Cable Company. He was a Fellow of the American Institute of Electrical Engineers and a member of the American Society of Mechanical Engineers.

His interest in all of these associations was active, intelligent, and effective. He brought to their counsels instinctive good judgment and wide acquaintance with men and affairs. Of a perfect serenity of temper, unruffled even by illness and overwork, he united the highest integrity with sound judgment and great amiability of character. Unqualifiedly impatient and indignant at any form of crookedness, he was unwilling to do anyone an injustice, even in casual conversation. His contribution to good citizenship is a cause for gratitude. A good man has died and left the priceless heritage of a good name, and a distinguished example of unselfish devotion to every duty, both public and private.

FRANCIS R. HART.

LYMAN CHURCHILL NEWELL¹ (1867-1933).

Fellow in Class I, Section 3, 1930.

The writer of this memoir was closely associated with Professor Newell first as a fellow student for three years at The Johns Hopkins University and later in many of his activities in promoting organizations to further the development of chemistry. This experience led to a very high regard for his executive ability, his genius as a teacher of science, and his unselfish, unlimited devotion to work for others. Professor Newell's chief interest lay in the improvement of the teaching of chemistry, and in the history of the science. In both fields he applied the methods of research and his findings and conclusions are recorded in many publications. He was the author of ten text books which reflected his study of pedagogical methods based on intimate contact with his students. His books commanded large sales and their use improved markedly the teaching of chemistry in both high schools and colleges.

His interest in the history of chemistry led to detailed study of the development of the science in America. Research brought to light many facts of importance and interest. He was the acknowledged authority in this field. In connection with this work Professor Newell built up a rare collection of books, manuscripts, letters, autographs, portraits, and medals. His lectures to his students in the history of chemistry were made vital by illustrations from his collections.

Professor Newell broadened his influence by leadership in the activities of the American Chemical Society in the History of Chemistry and in Chemical Education. He served as Chairman of the Divisions of the Society devoted to these subjects. His enthusiasm inspired enthusiasm and he brought into the divisions men and women who became active workers. He was the editor of a department in the *Journal of Chemical Education* and did much to increase the value and influence of the publication. For many years Professor Newell was a dominant figure in the New England Chemistry Teachers' Association, an organization which concerned itself with the teaching of chemistry in high schools.

¹ See also "American Contemporaries: Lyman Churchill Newell" by Tenney L. Davis, *Ind. and Eng. Chem.*, 24, 1082 (1932) and articles expressing appreciation of Professor Newell and his work by E. O. Holmes, J. P. Mason, A. A. Ashdown, and M. J. Ahern published in *The Nucleus of the Northeastern Section of the American Chemical Society*, January 1934.

His executive ability was demonstrated for many years by his activities in the Northeastern Section of the American Chemical Society. He served as Chairman of the Section and as chairman of many important committees. He brought to a successful conclusion his suggestion of the establishment by the Section of a medal, named in honor of Theodore William Richards, to be awarded for conspicuous contributions to chemistry.

Professor Newell had many interests outside of chemistry. He was a member of the New England Gladiolus Society and of the Harvard and the Brookline Musical Clubs. He had an attractive personality, a sense of humor, and a genial manner which made for him many friends.

Lyman Churchill Newell was born in Pawtucket, Rhode Island, September 19, 1867. He was awarded the Ph.B. degree by Brown University in 1890 and the Master's degree one year later. He taught for a year in the Pawtucket High School and then entered The Johns Hopkins University and was awarded the degree of Doctor of Philosophy in chemistry in 1895. He was instructor in chemistry at the Somerville English High School 1895-1898, and at the Lowell State Normal School 1898-1904. He was called in 1904 to the headship of the Department of Chemistry of Boston University, where he remained until his death December 13, 1933.

JAMES F. NORRIS.

ERNEST FOX NICHOLS¹ (1869-1924).

Fellow in Class I, Section 2, 1913.

Ernest Fox Nichols was born in Leavenworth, Kansas, June 1, 1869. He completed his undergraduate education at the Kansas Agricultural College, receiving there the degree of Bachelor of Science in 1888. Graduate study of physics was continued at Cornell University under Professor E. L. Nichols, where he took his Master's degree in 1893. In 1892 he was appointed professor of Astronomy and Physics at Colgate University, which position he held during

¹ A very complete and appreciative biographical account of the life and work of Ernest Fox Nichols was prepared by Professor E. L. Nichols and presented at the meeting of the National Academy of Sciences in 1925. See the Biographical Memoirs of the Academy, Vol. 12, p. 99 (1929).

the following six years. During 1894–1896, however, he was granted leave of absence to continue his studies at the University of Berlin and while there he began his fundamental work on residual rays. Upon his return to this country he was awarded the degree of Doctor of Philosophy by Cornell University.

In 1898 Dr. Nichols was called to Dartmouth College as head of the Department of Physics. There he carried on investigations of great importance in the field of radiation. The summers of 1898 and 1900 were spent at the Yerkes Observatory upon invitation of its director, Dr. George E. Hale. Here, with the radiometer which he perfected and an horizontal telescope, he measured for the first time the heat received from several of the brighter stars and from two of the planets. During this same period, in collaboration with his associate, Professor Gordon F. Hull, he not only detected but measured with precision the pressure of light, obtaining results which confirmed completely the predictions of Maxwell's electromagnetic theory. This outstanding contribution was announced at the Denver meeting of the American Association for the Advancement of Science, August 29, 1901. Working quite independently of Nichols and Hull, and unknown to them, Lebedew—at the International Congress of Paris in the summer of 1900—announced that he had detected light pressure of an order of magnitude predicted by theory but no numerical data were given at that time. The quantitative confirmation of the theory is therefore due to Nichols and Hull. The importance of these contributions was recognized by the American Academy of Arts and Sciences in 1904 by the award of the Rumford Medal to Dr. Nichols “for his researches on radiation, particularly on the pressure due to radiation, of the heat of the stars and the infra-red spectrum.”

In 1903 after five years of productive work at Dartmouth College, Nichols accepted a call to Columbia University as Professor of experimental physics. The winter of 1904–1905 was spent on leave of absence at the Cavendish Laboratory, Cambridge. His researches during this period were directed to the extension of the spectrum still farther into the infra-red by means of residual rays obtained from various reflecting surfaces. The summer of 1906 saw him pursuing his investigations at the Carnegie Solar Observatory on Mount Wilson. There he measured the absorption of sun light in the infra-red region of the spectrum and proved that beyond $51\ \mu$, waves are completely lacking.

In 1909 Dartmouth College recalled Dr. Nichols, this time as President. This necessitated giving up his cherished scientific work, and for seven years he devoted himself to the upbuilding of the college, which prospered and grew under his administration. In 1916, however, he decided to resign and return to his scientific work, and Yale University at once offered him a Professorship.

As soon as this country entered the world war research work was again interrupted, for Dr. Nichols tendered his services to the National Research Council and under the Navy Bureau of Ordnance devoted himself to problems of the national defense. After the conclusion of the war he was asked to become the director of research at the Nela Park Laboratory in Cleveland. As this involved no teaching and presented an opportunity for devoting himself exclusively to research in the field of light, he resigned his position at Yale and went to Cleveland. A few months later, however, he was elected to the Presidency of the Massachusetts Institute of Technology, which had become vacant through the untimely death of President Maclaurin. He was inaugurated in June, 1921, but almost immediately afterwards was stricken with a serious illness which necessitated his taking a long and complete rest. Upon the insistent advice of his physicians he reluctantly resigned the Presidency of the Institute the following November without having actively assumed the duties of the position.

After a year's rest he had sufficiently recovered to resume his scientific work and was welcomed back to the Nela Park Laboratory. There, in collaboration with Dr. J. D. Tear, he devoted his efforts to bridging the gap between the electrical and infra-red spectrum—the problem which, from his student days in Berlin, had been the goal ever before him. This problem he solved and on April 29 at the spring meeting of the National Academy, the day after its new palatial home had been formally dedicated, Dr. Nichols—while presenting the results of this research before a large gathering of his colleagues—hesitated a moment in his exposition and very quietly sank down on a seat on the platform, dead. Thus passed away one of the most skilful experimental physicists of our generation, at the moment of announcing the successful solution of the problem to which he had devoted the greater part of his life. As his former teacher, Professor E. L. Nichols, has truly said—"What more fitting departure could a man of science desire?"

Dr. Nichols was the recipient of the following honorary degrees: D.Sc., Dartmouth College 1903; LL.D., Colgate University 1909; LL.D., Clark University 1909; LL.D., Wesleyan University 1909; LL.D., University of Vermont 1911; LL.D., University of Pittsburgh 1912; LL.D., Dennison University 1914; LL.D., Dartmouth College 1916.

He held membership in many academies and scientific societies, an enumeration of which is to be found in "American Men of Science."

Dr. Nichols' contributions to science have placed his name high among those of the leading physicists which this country has produced but his high ideals and loyalty, his genial personality and delightful sense of humor are the human qualities by which he is remembered by his colleagues and host of friends.

In 1894 he married Miss Catherine Williams West, of Hamilton, New York, who with a daughter, survives him.

H. M. GOODWIN.

GEORGE HERBERT PALMER (1842-1933).

Fellow in Class IV, Section 1, 1912.

George Herbert Palmer was born in Boston March 9, 1842. He died May 7, 1933, having passed by two months his ninety-first birthday. He had long been the oldest in years and in academic seniority on the list of the Harvard faculty, from whose active membership he retired in 1913. As a child he was physically feeble, his schooling frequently interrupted: in spite of this, after two years at Andover Academy, which he entered at twelve, and an interval in the wholesale dry goods trade, he entered Harvard at the age of 18 and graduated in regular course in 1864.

Having decided, during an experimental year of teaching in Salem High School, that his future course would lie between philosophy and letters, he entered Andover Theological Seminary in 1865, receiving the degree of B.D. in 1867. The best opportunities for advanced study in philosophy were to be found at that time in the theological schools, inasmuch as graduate schools in connection with the universities were little developed. Palmer never actually entered the ministry, though he frequently and naturally served as minister at the Harvard chapel and elsewhere; and throughout his life, his thinking easily related itself to theological conceptions. German

philosophy, which he had known chiefly through the writings of Coleridge and F. D. Maurice, attracted him; and he spent in Germany parts of two years. In 1870, President Eliot, then in the second year of his administration, offered him an appointment as tutor in Greek under Professor Goodwin; he entered upon this work in the fall of that year. His association with Harvard College thus spans nearly the whole of the two administrations of Eliot and Lowell.

When he began his teaching, faculty meetings consisted of some thirty men at a long table, with President Eliot at one end. Each member of this small group carried in mind the major part of the business of the university. To the end of his life, Palmer retained the mental habit thus formed of responsibility for the institution as a whole. Though he was especially identified with the department of philosophy, he served at different times in five departments, including English, Fine Arts, Greek, Theology. He will be remembered for his contributions to letters, his translation of the *Odyssey*, his *Life of Alice Freeman Palmer*, his edition of George Herbert, as well as for his contributions to philosophy.

He had an active part in the building of the department of philosophy, which included when he entered it in 1872 as instructor, one full professor, Francis Bowen. Palmer aided the coming of William James against some opposition within the department; he and James discerned the outstanding promise of Royce, then an instructor of English in California, and secured him for Harvard by taking successive sabbatical leaves; this trio produced Santayana and Benjamin Rand, and attracted Muensterberg from Germany.

Palmer's teaching in philosophy began with the required elementary course; but in 1879 he offered a course in systematic ethics which in 1884 became the "Philosophy 4" with which his fame as a teacher was especially associated. Into his lectures he carried the qualities which showed the lover of literature and of the classics. His lectures were meaty, and they had pace: they were delivered without hurry, hesitation, or repetition. They constituted well-arranged parcels of thought, with a clarity and pedagogical excellence which often had the paradoxical effect of concealing their actual depth. Clarity, however, was for him an obligation, the first point of honor in the relation of teacher and student; and his perfection of form was the result of severe effort. At first so shy that he could hardly face a

class, and with painful hesitancy for words, he brought himself by the discipline of a relentless will, characteristic of his whole life, to an extraordinary mastery of extempore speech. His utterance abounded in aphorisms, which, as President DeWitt Hyde said, "continued to glow in the dark of the mind."

Perhaps the highest reaches of his power as a teacher were in his biographical sketches of the great philosophers. Here his powers of appreciation and criticism had full play. His elective course in the history of philosophy had as many as four hundred students, a remarkable number in the Harvard of 1890-1900.

Power to reach objective estimates of men, including himself, was one of his marked characteristics. In view of his own belief that the imperfect has its peculiar glories, he was inclined rather to dwell upon the defects of the character he was dealing with than to minimize them: he was a foe of every excess of praise. Owing in part to the relentless realism of his judgment he was widely sought as counsellor in the placing of men. It is a large part of the secret of his own success that he knew and respected his own limitations. Though he was one of the first to respond to the spirit of Eliot's administration by offering systematic courses of his own devising in place of the prevalent text-book-recitation scheme, and although his own works in systematic ethics,—*The Field of Ethics*, *The Nature of Goodness*, *The Problem of Freedom*, *Altruism*,—are of lasting value, he conceived his own function as that of a critic rather than that of a constructive thinker. And it is as a teacher, transmitting his creative appreciations, that he has had his primary effect.

In 1889 he became Alford Professor of Natural Religion, Moral Philosophy, and Civil Polity. He received honorary degrees from Harvard, Michigan, Union, Dartmouth, California, and Western Reserve.

Though his means were never large, he was a generous and discriminating giver,—to Wellesley a fine collection of first editions of English classics, to Harvard, collections of George Herbert, and of rare editions in philosophy.

Of less than average height and hampered in vision, the impression of his personality was nevertheless one of singular force; this was in part the power of large practical sagacity; it was also the power of clarity, of goodness, and of self-mastery.

WILLIAM ERNEST HOCKING.

EDWARD DYER PETERS (1849-1917).

Fellow in Class I, Section 4, 1914.

Edward Dyer Peters was born in Dorchester, Massachusetts, on June 1, 1849. He died in Dorchester on February 17, 1917. He attended the Episcopal School for boys at Cheshire, Connecticut, and when he was sixteen his father took him to Europe. In 1865, he entered the Royal School of Mines at Freiberg. He returned to the United States in 1869 and settled in Denver, Colorado. In 1871, he was superintendent and metallurgist of the Caribou Mine, at the time the largest silver mine in the country, a position which he resigned in 1872 to accept an appointment from the governor of the territory as territorial assayer for the southern part of Colorado. In the fall of the same year, he built the Mount Lincoln Smelting Works. In 1874, Peters returned to the East, believing that the ores of Colorado had been worked out and that there was little future for mining engineering. He entered the Harvard Medical School, graduating in 1877, first in a class of one hundred and sixty. He practiced medicine in Dorchester until 1880, when he returned to his original profession. In 1881, he married his cousin, Anna Quincy Cushing, and after his marriage we find him associated successively with the Orford Nickel and Copper Company and with the Ely Mine in Vermont. In 1884, he erected the first successful concentrating and smelting work of the Parrott Silver and Copper Company. From 1888 to 1890, he was the general manager of the Canadian Copper Company of Sudbury, Ontario. In 1892, he was called to Tasmania to report on the Mount Lyell Mine. In 1893 and 1894, he worked in Paris at the École des Mines. Upon his return, he continued actively in the practice of his profession until 1904, when he was invited to give a course of lectures on the metallurgy of copper at Harvard University, being appointed Professor of Metallurgy in the fall of that year and Gordon McKay Professor of Metallurgy in 1909, a position which he held until his death.

Professor Peters made notable contributions to the metallurgy of copper through technical papers and the publication of three important volumes:—Modern American Methods of Copper Smelting, Principles of Copper Smelting, and The Practice of Copper Smelting. These were standard books, of which many editions were sold. He

was by general consent the most eminent authority on the metallurgy of copper. His fine upright nature, honesty, and sincerity endeared him to his many friends. He was a gentleman of the old school, courteous, just and tolerant, an exponent of Christian virtues.

ALBERT SAUVEUR.

ARTHUR KINGSLEY PORTER (1883-1933).

Fellow in Class IV, Section 4, 1922.

In 1883 a rare and beautiful spirit came into the world when Arthur Kingsley Porter was born in Stamford, Connecticut. His father was Timothy Hopkins Porter, a banker in Stamford, and his mother was Maria Louisa Hoyt, one of the first women to study at Vassar.

He went to school at King's Academy at Stamford and at the Browning School in New York. He received his degree of Bachelor of Arts from Yale in 1904. After that he went to the Columbia Architectural School for two years and then spent two years of study in France and Italy.

At the age of twenty-five he published his first book, "Medieval Architecture," in two volumes, a remarkable book for a man of his age, and full of promise. Two years later, in 1911, he published his next book, entitled "Construction of Lombard and Gothic Vaults," in which he grappled with problems of significance.

In the following year, 1912, he married Lucy Bryant Wallace. Her untiring energy and complete devotion to him and his work played an important part in his later successes. Among other things she became an admirable photographer and thus helped greatly on that side of his work, which counted so much.

During the years 1915 to 1917 he worked on and published his notable four volume book on "Lombard Architecture." He furnished substantial proof that the ribbed groined vault, on which Gothic architecture depends, was created first in Lombardy, to travel from there to France.

In 1915 he was called to Yale as lecturer in the History of Art, and in 1917 he became assistant professor. In 1920 Harvard offered him a professorship of art with the understanding that he need teach only a small part of the time and that he might feel free to continue

his travels, researches, and publications. In 1924 he became the first incumbent of the newly-created William Dorr Boardman Professorship of Fine Arts.

When he moved to Cambridge he bought Elmwood, formerly the house of Elbridge Gerry, one of the signers of the Declaration of Independence, and later of James Russell Lowell, the poet. The Porters added fresh distinction to the venerable house already rich with associations. They entertained students, friends, and distinguished visitors. Music and poetry played their part at these gatherings. This house he bequeathed to Harvard, subject to a life estate of his wife.

In 1923 Porter was sent by Harvard as exchange professor to Paris and the provincial French universities, and in 1924 as visiting professor to Spain.

As the years went on his reputation grew, and eventually he was recognized in both Europe and America as America's foremost mediaevalist. He was the only American who was asked by the French Government to serve on the commission to inspect the precious early buildings injured in the World War. I remember meeting him in Paris in 1920 on a bleak October day, and he and Mrs. Porter invited me to go on an inspection tour with them through the desolated fields, forests, and ruins. It was then that Porter told me of a thought which absorbed him, suggested by Bédier's book on the development of the mediaeval French epic along the pilgrimage roads. If the literature developed in this way, why not sculpture and architecture also? He followed the clue for years and in 1923 published his largest and probably his most important book, "Romanesque Sculpture of the Pilgrimage Roads," in ten volumes, one of text and nine of well chosen illustrations almost entirely from photographs taken by himself and Mrs. Porter, many of them unique and of great beauty.

He turned his attention to Greece, and he and Mrs. Porter went there for several months in 1923 to continue his researches in the field of Byzantine art in preparation for a course which he was to give at Harvard. Again in the summer of 1925 they went to Greece and chartered a Greek freight sloop and cruised among the Aegean Islands. On his return journey through Europe his valise was stolen. In it were the negatives of his photographs and a large part of his

notes. The world probably lost a valuable publication as a result of this theft.

His next book appeared in 1928. It was entitled "Spanish Romanesque Sculpture" and represented years of research in Spain. He showed that there had been a continuous development of sculpture in Europe, and called attention particularly to the pre-Romanesque sculpture of Spain and to the importance of some of the masterpieces of the eleventh century.

He was an indefatigable scholar. Eighty of his articles appeared in various periodicals and other collective works published in Europe and the United States. Most of these were on archaeological subjects, but some of them were essays and book reviews.

He was given honorary degrees and was made a member of ten learned societies in America, France, England, and Spain; and he received the Grande Médaille de Vermeil from the Société Française d'Archéologie for his book on "Lombard Architecture."

His enquiring mind was never content to settle into a groove of any sort, and he became fascinated with the idea of studying the part that Ireland played in the development of mediaeval art and its relation to Egypt, to Spain, and to the other countries of Europe. The Porters went to Ireland and he bought a demesne among the wild and romantic moors of Donegal. He was attracted in many ways to this austere and beautiful place, and not the least of its charm was that the traditional birthplace of Columcille was on his land. Here in Glenveagh Castle, a Victorian mansion, they entertained their friends including Irish scholars, artists, and poets. The Porters also built a cottage on the Island of Inishbofin off the north coast of Donegal. Miles away the lonely extent of the Atlantic was broken by the dim outline of the Island of Tory, which looked like a dream castle emerging from the northern sea.

In 1931 he published his last book, "The Crosses and Culture of Ireland," based on a series of lectures he had given at the Metropolitan Museum in New York. He consented to repeat these lectures at the Fogg Museum in the winter of 1929-30. Others had explored this field before him; but it is perhaps fair to say that no one had approached the subject with so wide a knowledge of the related fields of the mediaeval art in all the other countries of Europe.

In July, 1933, Mr. and Mrs. Porter went to spend a night at Inish-

bofin, where there are rocky cliffs and powerful tides. Next day there was a portentous thunderstorm and a heavy sea was running. By some cruel accident, the exact cause of which we shall probably never know, Mr. Porter fell to his death.

"When beggars die there are no comets seen,
The heavens themselves foretell the death of princes."

Kingsley Porter was a modest and somewhat shy person, tall and spare. He was a strong walker and swimmer. And when he was young he used to hunt big game during his vacations in Newfoundland and in Canada. It was remarked of him that it was unusual to see a scholar of such great industry and learning who was so much at home out of doors. He was friendly in a quiet way, though in general somewhat reserved. He had the rare combination of a poetical and scholarly nature with the capacity of a business man. He showed clear-headed intelligence and good judgment in handling his affairs.

He was brilliantly successful as a teacher. In his earlier years he gave some general courses at Yale; but later at Harvard he developed a style of teaching which was of a more intimate and congenial nature. Here he talked on the subjects so dear to his heart, to a group of a dozen students seated around a table. If more than twelve joined his class, he would repeat the lecture in two consecutive hours so that the photographic material could be properly seen and understood. He gave of his best to his students, and developed a group of disciples who are carrying on his work. He gathered together a collection of original works of art, an admirable library, and a valuable collection of photographs at Elmwood. These were placed at the disposal of his students for use in their studies. He was a good linguist and, besides the usual classical and modern European languages, including Spanish, he learned Catalan and Scandinavian; and even acquired a knowledge of the ancient Celtic language.

Professor Post says of him: "It was highly characteristic of Porter's mental curiosity and alertness that he should constantly have changed his basis of interest, partly because he so nearly exhausted the possibilities of each problem that he approached."

As an example of the incisiveness of his mind:—At a time when European archaeologists vaguely thought that the architecture and sculpture of the ruined Abbey of Cluny were of the twelfth century,

Porter divined that they were created in the eleventh century, and from this fact he was able to draw significant conclusions. Professor Kenneth Conant was able to prove later in the course of his excavations and researches that Porter was right.

Just before his death he was preparing a paper on pagan sculpture in Ireland, and this brought him to the threshold of the prehistoric age.

Thus his mind might be compared to a searchlight that flashed in one direction clearly illuminating that field, then turned its powerful light on another region, and then to still another, revealing to the world certain new aspects and the relation of these fields to each other as one by one they emerged from partial shadows.

Besides his monumental books which made his fame, and his great array of magazine articles, he published three other short books. In his series of essays entitled "Beyond Architecture," first published in 1918, he gives glimpses of his enthusiasm for the civilization of the thirteenth century, when the community created great works for the glory of God. He contrasts the wonders of that civilization with the often selfish passion for individualism, the intellectual laziness of our peoples, and the damage that the machine age has done to our aesthetic sense. "The Virgin and the Clerk," one of his short plays, was performed with success at the Carnegie Institute in Pittsburgh. The other play, "The Seven Who Slept," was based on an early legend. It produces a sense of aloofness and unearthliness. In "The Crosses and Culture of Ireland," which proved to be his farewell message, he gives a stimulating picture of the sunrise land of Egypt sending forth some of its thought and spirit to Ireland, where the sun sinks into the western waters. The Irish, he says, were probably the oldest race in Europe, unconquered by the Romans and keeping pure their primitive characteristics. He emphasizes the potency of the influence of the Irish monasteries which spread over Europe from the sixth to the ninth centuries. The poetical and mystical sagas set vibrating chords in his kindred nature, and he rejoiced in the early legends and visions of these dwellers by the sea.

EDWARD W. FORBES.

AUGUSTO RIGHI (1850-1920).

Foreign Honorary Member in Class I, Section 2, 1912.

Righi was born at Bologna August 27, 1850, and he died there June 8, 1920. Educated at the University of Bologna, he taught physics there for a time as a young man, became professor of physics at the University of Palermo in 1880 and at the University of Bologna in 1903, remaining in this position till his death. He was made a Senator in 1903.

He was probably the leading Italian of his generation in the field of pure physics. He was an active investigator and a skillful expositor of physical phenomena and laws.

In the early days of electromagnetic radiation development he invented an electric oscillator which was widely used for the production of Hertzian waves. It is said that Marconi as a young man visited the laboratory at Bologna and saw the radiation apparatus and experiments there, but it does not appear that he was ever a student under Righi in the regular way.

Righi worked a great deal experimentally on the phenomena produced by action of a magnetic field on various forms of the electric current. He, and Leduc independently, discovered one of the four "transverse effects" of the magnetic field, the production and maintenance of a temperature-gradient at right angles with the direction of heat-flow in a metal.

He won a 10,000 lire prize of the Accadèmia dei Lincei and the Hughes medal of the Royal Society of London, of which Society he was a foreign member. Sir Oliver Lodge, in *Nature*, vol. 105, p. 753, says that Righi succeeded Lord Kelvin as a foreign member of the Royal Academy of Science at Upsala.

In person Righi was both genial and impressive.

EDWIN H. HALL.

ARTHUR BLISS SEYMOUR¹ (1859-1933).

Fellow in Class II, Section 2, 1892.

Arthur Bliss Seymour, of New England Puritan stock on both sides of his family, was born January 3, 1859, at Moline, Illinois. His

¹ Compare the biography by L. R. Jones in *Mycologia* 26: 279-290. 1934. (Portrait, Bibliography and Exsiccati.)

father, a direct lineal descendant of a Richard Seymour who came from Hertfordshire, England to Hartford, Connecticut in 1639, had moved from Massachusetts to Illinois in 1853. He married Anna Julia Conkling of Champaign, Illinois in 1886. He died at Waverley, Massachusetts, on March 29, 1933.

Mr. Seymour was a naturalist, with plants as his main, absorbing interest. His education as a botanist began in boyhood under fortunate, informal tutelage amid the rich flora of the prairies of Illinois. His academic training in his beloved subject was carried out at the University of Illinois under the stimulating and markedly formative direction of a notable teacher and investigator, Professor Thomas J. Burrill, immediate associations with whom lasted from 1877 to 1883. Seymour was graduated from the University of Illinois in 1881 and received from the same institution the degree of Master of Science in 1886.

After a few years of service as botanist to the Illinois State Laboratory of Natural History, Mr. Seymour came to Harvard University in 1883 as assistant to Professor W. G. Farlow. He served in that capacity for two years, then taught in the University of Wisconsin for one year (1885-6), and in 1886 was called to Harvard University as assistant in the Cryptogamic Herbarium. There he continued to the end.

Mr. Seymour entered on what proved to be his major life work with rare enthusiasm, and to this abounding enthusiasm were added a kindly spirit and a persistent zeal that continued undiminished until death claimed him. The Cryptogamic Herbarium at the time he joined Professor Farlow was in its beginnings. He lived to see its rise to a foremost world position, and in its development he played a very important part. On him fell the responsibility of sorting out and making easily available the data on the rich collections being assembled by Professor Farlow and simultaneously building up a complete catalogue of bibliographical references covering the rapidly expanding field of American mycology. This was a prodigious undertaking and successful accomplishment called for adequate training, a workable system, an unusual aptitude, and exacting faithfulness. Model, surprisingly complete indexes are a heritage of his labors—magnificent contributions of permanent value to botanical science.

Based on these indexes, three great works have been issued from

the Farlow Herbarium, namely,—“A provisional host index of the fungi of the United States” (1888–1891) (Farlow and Seymour); “Bibliographical index of North American fungi” volume I, part 1 (1905) (Farlow); and “Host index of the fungi of North America” (1929) (Seymour). The indexes, indispensable as they are to mycology, are being continued. They will ever remain a monument to the memories of Professor W. G. Farlow and Mr. A. B. Seymour.

J. H. FAULL.

SAMUEL WESLEY STRATTON (1861–1931).

Fellow in Class I, Section 4, 1923.

Samuel Wesley Stratton, internationally known as the creator of the Bureau of Standards, was born on a farm at Litchfield, Illinois, on July 18, 1861. He was the son of Samuel and Mary B. (Webster) Stratton, and on the paternal side his lineage is traced to the early settlers of Virginia. The son early shared in the farm labor, and here acquired the habits of hard work and intensive study of his tasks. From boyhood he showed the keenest interest in mechanics, and he found enjoyment in maintaining the machinery of the farm in perfect condition, and in contriving mechanical inventions to make easier the many home labors which a varied farm life demands.

He attended the district school and later the limited village “high” school in his native township. His youthful ambition was to become a thorough machinist. Even at this time neighboring farmers recognized his skill and sought his help.

Through his step-brother he learned of the mechanical shops at the new Illinois Industrial University (now the University of Illinois), where students could earn a part of their school expenses. Greatly desiring such an opportunity, he induced his father to permit him to attend for a single year. Before doing so he worked for nearly two years to earn the needed money, and in 1880 began his college life as a special student at Urbana. After a few months at the university he was convinced that engineering must be his life work. He earned his way from year to year, at the same time carrying extra courses, and completed with distinction his course for the S.B. degree in Mechanical Engineering in the Class of 1884. He later returned to Urbana as Instructor in Physics and Mathematics, but soon confined

his work to physics alone, and in 1890 was designated to establish and take charge of a new course in Electrical Engineering. For the next two years he was Professor of Electrical Engineering.

In 1892, he was elected associate professor of physics at the newly organized University of Chicago. Here he became associated with Michelson in his investigations on the speed of light, and also gave much attention to the applications of physics to engineering. In addition, he planned and supervised construction of the Ryerson Laboratories.

Always interested in military affairs, he joined the Naval Militia and in 1898, at the outbreak of war with Spain, held the position of commander. With the rank of Lieutenant, he entered the naval service, his unit being assigned to the "Texas." He saw at once the need for standardization of equipment for war vessels, and prepared a brief report thereon.

Two years later, in 1900, he was asked by Secretary of the Treasury, Lyman J. Gage, to prepare a report for a national Bureau of Standards. A bill, authorizing the establishment of the Bureau resulted and was presented to Congress. Dr. Stratton skillfully managed the many hearings and demonstrations before the congressional committee, and the bill was passed on March 3, 1901. The Bureau of Standards thus became an actuality. On the insistence of Secretary Gage, Dr. Stratton became its first Director. His vision of the usefulness and functions of such a Bureau was so clear that from the beginning the work of the Bureau expanded greatly.

In 1903 the Bureau was transferred to the Department of Commerce, extending the opportunity to bring research directly to the aid of commerce and industry. Under his broad minded direction invaluable service was given to a great number of industries. He had the gift of securing first the confidence and then the cooperation of industrial leaders and men of vision in many technical fields. Dr. Stratton and the Bureau promptly became important factors in the International Conference on Weights and Measures, and in manifold advisory committees for industry. Under his direction the Bureau grew to one of the great research centers of America.

With the advent of the World War invaluable service was rendered. As an outstanding example, his work on optical glass, in coöperation with American manufacturers, made possible glass of superior quality and rendered American industry independent of foreign sources.

Dr. Stratton never lost interest in technical education, and when he was invited to become the President of the Institute of Technology in 1923 he accepted, in the belief that here he could render a special service both to the Institute because of his knowledge of the needs of industry, and to American industry by participating actively in the training of men of the type who would become the leaders in the industrial fields. He believed firmly in sound engineering training combined with the appreciation of research. His interest in the problems of student life and welfare at Technology found expression in his part in securing a new infirmary with adequate physical examinations and medical supervision, new dormitories with modern conveniences for comfort and hygienic living and a high social standard, and emphasis on human relations in business and industry.

For many years the position of President of the Institute had made exacting and almost impossible demands on the energies of its incumbent. In 1930 a reorganization of administrative policy was effected, whereby Dr. Stratton became Chairman of the Corporation, and Dr. K. T. Compton was elected to the office of President. Thus, two men shared the responsibilities which one had always borne hitherto. This harmonious arrangement was of brief duration, however, for Dr. Stratton died instantly on October 18, 1931, while in the very act of dictating a warm eulogy of his friend Edison, who had died earlier the same day.

Outwardly reserved, and often unassertive to the point of shyness, Dr. Stratton had innate qualities that greatly endeared him to those fortunate enough to know him well. His great modesty, his generosity and the desire to give rather than take credit were strongly developed. In his own home one saw the man at his best, for he was the perfect host. Associates and guests who penetrated his natural reserve readily became steadfast admirers, finding him always a man of strong personality, of forceful and unimpeachable character, and of unswerving loyalty. They also discovered hidden depths of sentiment and an immeasurable fount of specialized knowledge and interests in many fields. He was versed in textiles, china, glass, and antique furniture, as well as mechanical devices of every sort and the latest technical advances in physics and engineering. In his rare hours of freedom from administrative duties, he found particular enjoyment in constructing with his own hands pieces of scientific apparatus or in

building cabinets or furniture. Whether working with wood or metal his technique and attention to detail were meticulous and faultless. In this avocation he not only found relief from the greater problems and cares incident to his office, but his work expressed that striving for exactness and high quality, even to perfection, which characterized his life.

His memberships included not only this Academy, the National Academy of Sciences, the American Philosophical Society, and the great engineering societies, but he was also Chairman of the International Conference on Weights and Measures, and a chevalier and an officer of the Legion of Honor.

Many honors came to him from universities at home and abroad, including the Dr.Eng. from the University of Illinois, his *alma mater*; D.Sc. from the University of Pittsburgh, Cambridge, and Yale; Ph.D. from Rensselaer; and LL.D. from Harvard. Among other distinctions, he was awarded the Cresson Medal of the Franklin Institute and the Public Service Medal of the National Academy.

He was great not only in his desire to serve his people and in scientific achievement, but in character and loyalty to his friends.

SAMUEL C. PRESCOTT.

GEORGE FILLMORE SWAIN¹ (1857-1931).

Fellow in Class I, Section 4, 1888.

George Fillmore Swain, whose death occurred at his home on July 1, 1931, was distinguished as an educator, an engineer, and a public servant. He was born in California on March 2, 1857. His ancestors came from New England and he, himself, came to Boston as a student at the Massachusetts Institute of Technology, from which he was graduated in 1877. In 1877-1880 he was a student at the Royal Polytechnic School in Berlin and then returned to Boston, where he lived until his death.

His first professional duties were as a Special United States Census Agent upon the investigation of water power along the Atlantic slope for the 1880 census. This work was followed by brief engagements in hydraulic engineering at Lowell and Lawrence. General Francis A.

¹ Further details of Professor Swain's life are given in the Memoir by C. Frank Allen, Proceedings of the Boston Society of Civil Engineers. June, 1932.

Walker, the Director of the Census, during Swain's service, was appointed President of the Massachusetts Institute of Technology in 1881, and soon after his appointment selected Swain as an instructor in Civil Engineering. He served in this position but a brief time and was then appointed an Assistant Professor. Upon the retirement of Professor Vose, he was, in 1887, at the early age of 30, appointed Hayward Professor of Civil Engineering.

The failure of the Bussey Bridge in Roslindale in 1887 and Professor Swain's clear analysis of the cause, proved conclusively his outstanding ability in the field of engineering and led to his appointment by the Massachusetts Railroad Commission as its first expert engineer, which position he filled for many years in conjunction with his Technology professorship. His duties for the Railroad Commission included inspection of existing railroad bridges and approval of plans of new bridges throughout the state. The experience thus gained was reflected in his teaching, giving him an authoritative standing in the theory and practice of bridge engineering and establishing him at an early age as one of the outstanding engineering teachers of the country, a standing which he maintained until his retirement from active teaching.

Opportunity for another public service came to him in 1894 through his appointment to the newly organized Boston Transit Commission, upon which he served for twenty-five years, the last five years as Chairman. The pioneer work of this Commission in building the first electric railway subway in this country was notable and towards this he contributed an important part.

It would seem as if the duties of these various fixed positions would have occupied his full time and energy, but his strong power of concentration, clear thinking and confidence in the soundness of his reasoning and conclusions enabled him to make notable successes, not only in all of these fields, but also in numerous miscellaneous engineering projects in which he participated.

In 1909 he resigned from the Massachusetts Institute of Technology to accept appointment at Harvard as the first Gordon McKay Professor of Civil Engineering, where he continued his active teaching until his retirement as Professor Emeritus in 1929.

One of the rewards of success in any professional field is the recognition of one's associates and this was given Professor Swain in

liberal measure. He early served a term as president of the Boston Society of Civil Engineers and in 1913 was elected for the usual one-year term as President of the American Society of Civil Engineers, the oldest of the national engineering societies on this continent. To both of these societies he contributed liberally through his papers and personal services and was later elected as an honorary member of each.

New York University conferred upon him the honorary degree of LL.D. in 1906 and the University of California gave him the same degree in 1918. In 1928 he was the first recipient of the Lamme Medal given by the Society for the Promotion of Engineering Education for "accomplishment in technical teaching or actual advancement in the art of technical training."

Perhaps the most notable factor in Dr. Swain's teaching was his ability to reduce apparently complicated problems to terms so simple as to be easily understood by the ordinary student. The application of complicated mathematical formulas to the solution of simple structural problems, which was common in the earlier treatises on the subject of bridge engineering, always impressed him as unnecessary and convinced him that the authors did not really understand the topics which they were presenting.

While not a voluminous writer, he contributed to engineering journals numerous papers of high importance in the field of structural engineering and in the latter part of his life began a treatise in four volumes dealing with structures and materials, of which three volumes alone were published, his final illness preventing the completion of this important work.

CHARLES M. SPOFFORD.

JOHN ELIOT THAYER (1862-1933).

Fellow in Class II, Section 3, 1912.

The town of Lancaster, Mass. runs mostly along a single street for a mile or more and in its southern part stands the beautiful Thayer Museum of Ornithology, where John Thayer's huge collection of North American Birds was housed.

In a part of the world where rural centers long ago lost their cultured leaders and much of the old social tradition, John Thayer stands out as the finest example of what a New England country gentleman

ought to be. Indeed I can think of no other alive today who is filling quite the same niche that he did.

People of means now identify themselves almost wholly with city life and city interests, migrating to the country for short summer seasons, but John fixed upon Lancaster and his bird collections as almost his sole interests. In Lancaster he could be found winter and summer, in fair weather or foul, at his home on George Hill Road, and his fellow townsmen knew that in case of need his genial spirit would not fail them. He despised the city. In several places in his little diary of winter bird notes appear remarks such as this: "Had to go to Boston, how I hate it."

John Eliot Thayer was born in Boston in April 1862 and died in Lancaster July 22, 1933. His grandfather, Reverend Nathaniel Thayer, came to Lancaster from Hampton, New Hampshire, and began preaching there in 1792.

John graduated from the Hopkinson School in Boston and from Harvard with the class of 1885. He was first marshall of his class and one of its most popular members. He was given an honorary A.M. from Harvard in 1910. He married Miss Evelyn Duncan Forbes in 1886 and soon after, in 1888, moved into the large cheerful house on George Hill Road where with his family he spent the best part of his life. He is survived by Mrs. Thayer and five children, all married.

It seems rather odd to find that John was not actively interested in birds when he was a boy. I daresay he went through the usual stages of nest and egg collecting, but he seems to have dropped that interest and not to have taken it up again for some time. During his college period he, with his brother Bayard, maintained large kennels on George Hill Road where they raised fox terriers, deer hounds, and old-fashioned English bull dogs.

Next followed an absorbing interest in horses, which lasted through the middle nineties. In 1892 he bought the famous trotting stallion, Ralph Wilkes ($2.06\frac{3}{4}$) who died in 1895. Then followed a stallion named Electricity ($2.17\frac{3}{4}$). After this he purchased Baron Wilkes from a Kentucky breeder, reported at that time as the greatest living son of the renowned George Wilkes. At this time he was President of the New England Trotting Horse Breeders' Association and of the Worcester East Agriculture Society. In the late nineties John turned from horses to his permanent interest in birds.

At first his aim in ornithology was chiefly to get together a collection of all the local birds and he paid special attention to nests and eggs. Soon, however, his interest broadened so as to include the whole of North America. His collections were at first housed in several wooden buildings close to his house, but when these became unsafe and crowded he built the beautiful brick building in the town of South Lancaster and opened it to the public in November 1904.

In the visitors' book of the Thayer Museum appear the names of nearly all the ornithologists of the time, and it is interesting to note that, in spite of the fact that Lancaster thirty years ago was rather far off the beaten path, more than ten thousand visitors came to the museum in the first six years. After that, no tally seems to have been kept.

From now on John strove in every way to make his collections as complete as possible with large series of beautifully prepared specimens. He sent out collectors to Alaska, North Eastern Siberia, the Queen Charlotte Islands, Lower California, and Northern Mexico. In 1931 the whole of this collection was given to the Museum of Comparative Zoology at Harvard, but it is to be hoped that the Lancaster Museum, with at least a synoptic collection of mounted birds, will remain as a memorial to his enthusiasm. His library of ornithology was kept in his house, all save a few working books. This was sold and dispersed in 1931.

He had been an Associate of the American Ornithologists' Union since 1898 and was elected a member in 1905. All his important contributions were published with Outram Bangs as co-author. Among these may be mentioned the following:

Vertebrata of Gorgona Isle, Columbia; Aves, *Bul. M. C. Z.*, 46, no. 5, 1905.
Mammals and Birds of the Pearl Isles, Bay of Panama; *Bul. M. C. Z.*, 46, no. 8, 1905.

Vertebrata from the Savana of Panama; Aves, *Bul. M. C. Z.*, 46, no. 12, 1906.

Catalogue of Birds collected by W. W. Brown, Jr. in Middle Lower Calif.; *Condor*, 9, no. 5, 1907.

Descriptions of New Birds from Central China; *Bul. M. C. Z.*, 52, no. 8, 1909.

Aves from Szechwan, *Memoirs M. C. Z.*, 40, no. 4, 1912.

Notes on the Birds of the Arctic Coast of East Siberia; *Proc. New Eng. Zool. Club*, 5, 1914.

And now a few words as to the real John Thayer. You felt rather than saw his easy, beaming presence almost before you were aware that anyone else was in the room. His simplicity and directness, rarest of human attributes, were almost childlike, but they served to put any group of people immediately at ease. It was not what John said or did at a meeting, for he was far too modest to trumpet his own views; it was his comfortable presence that gave us all a sense of well-being.

He almost never traveled, and he never went on an ornithological collecting trip. Once when a youth he went to Europe and this, with several early journeys to the West and to Mexico, seem to have satisfied any slight curiosity for sight-seeing that he may have had. In one place in his winter bird diary he says, under March 17: "Off for Florida for two weeks. This is a mistake for the weather here (Lancaster) is like summer and what more can anyone ask?"

The winter and early spring birds seen around his orchards and at his feeding boxes gave him the keenest possible pleasure and these with his ever growing family (he could boast of eighteen grandchildren before he died), as well as positions in town, church, and library, and in his beloved museum, kept him busy every day of the year.

John enjoyed robust health up to the time of his severe illness early in 1928. His stocky athletic figure was full of energy, as the following quotation taken from his diary of July 22, 1926, when he was sixty-four years old, will prove. "Temperature 103°, the hottest day to date in the history of Boston. I worked all day in my orchard thinning apples. It was 100° in the shade of my house. I dismissed my help at four o'clock, but worked myself until six. Pretty good for an old fellow."

No notice of John Thayer's life would be complete without some reference to the positions of trust which he filled in Lancaster and elsewhere. He was the oldest Vice-President in point of service in the Massachusetts Forest and Park Association (Vice-President for Worcester County since 1908). He was also for many years a trustee of that ancient "Massachusetts Society for promoting agriculture," dating back to the eighteenth century. He served for at least ten years on the Executive Committee of the Massachusetts Fish and Game Association. He held the position of tree warden of Lancaster

ever since the State Tree Warden law went into effect in 1901. But that was not the beginning of his active interest in trees, for in his first report he says "For the last ten years, as a member of the Road Commission, I have taken this department under my care, so that in reality we have had a tree warden for a good many years."

As a member of the Board of Trustees of the Lancaster Town Library, he served from 1888 to 1933, without doubt the longest individual membership on any board in the town. But this is not the most important, for as the resolution upon his death says, it was his regularity of attendance, his generosity, tact, and cheerfulness that made his long service so noteworthy. As a trustee of the Clinton Hospital Association, as a Selectman of his own town for thirty years, as President of the Lancastriana Society, and as benefactor of his local church his memory will last for many years. During the War he served on the draft board of Division 14 for Clinton, Leominster, and Lancaster, financing the office work entirely from his own pocket. It would be impossible to list or even hint at his benefactions, save to say that after attending to charities at home in Lancaster, as was fitting, his name was found whenever worthwhile philanthropy asked for aid. But chiefly, his interests were in the domain of agriculture, horticulture, conservation, and the study of birds.

And so we must leave him, safe in the knowledge that his rare qualities will be perpetuated in the character of his descendants and in the hearts of his friends. He was in very fact the first and probably the last "John of Lancaster."

JOHN C. PHILLIPS.

WILLIAM CAWTHORNE UNWIN¹ (1838-1933).

Foreign Honorary Member in Class I, Section 4, 1900.

Unwin was born at Coggeshall, Essex, England, on December 12, 1838. He was brought up in an academic atmosphere, his father being principal of Homerton College. At the age of eighteen he was apprenticed to the engineer, Sir William Fairbairn. He there had training in research problems, and by study at night he obtained the degree of B.Sc. at the University of London in 1860.

¹ The following notice is abstracted from an obituary published in *Nature*, Volume CXXXI, May 13, 1933, pages 681-682.

In 1862 he became manager at the works of Messrs. Williams at Kendal, where the manufacture of Thomson's new vortex turbine had been begun; and in 1867 he was made manager of the engine department of the Fairbairn Engineering Company. In 1868 he began his teaching career as instructor in marine engineering in the Royal School of Naval Architecture; and in 1872 he was appointed professor of hydraulics and mechanical engineering at the Royal Indian Engineering College, Coopers Hill, which position he held until 1884.

In 1877 he published his textbook on *The Elements of Machine Design*, which had a wide use. In 1884 he was appointed professor of civil and mechanical engineering in the newly established City and Guilds Central Technical College, where he became associated with Armstrong, Henrici, and Ayrton.

In 1890 an American company appointed an international commission of five experts under the presidency of Lord Kelvin (then Sir William Thomson) to determine the best way of developing the power of Niagara and distributing it. The headquarters of this commission were at the Central College, and Unwin was secretary. In this service he made several trips to Niagara to study the conditions of the problem on the ground. He also carried out a long research on the flow of tidal waters in the Thames with reference especially to the pollution of the upper waters from the sewage of the London main outfalls.

In 1904 Unwin resigned his professorship but continued his engineering practice. He was on the council of the Institution of Civil Engineers, and took part in framing the new proposals relating to the preliminary training of the civil engineer. In 1911 he was elected president of the Institution and in 1915 elected president of the Institution of Mechanical Engineers and again in 1916.

During the war, at the age of seventy-seven, he served on the management board of the Metropolitan Munitions Committee.

He was awarded the Kelvin medal, was a fellow of the Royal Society, LL.D. of Edinburgh, honorary member of both American Societies of Civil Engineers and Mechanical Engineers, and an honorary associate of the Royal Institute of British Architects.

JOHAN HERMAN LIE VOGT (1858-1932).

Foreign Honorary Member in Class II, Section 1. 1915.

Johan Herman Lie Vogt was a pioneer in the scientific study of ores that have been deposited directly from molten rock. He was the first to apply the principles of physical chemistry to the genetic questions about these important ores, and, in so doing, greatly stimulated fruitful research on the origin of rock species in general.

Vogt was born on October 14, 1858, at Tvedestrand, Norway, and died at Trondhjem on January 3, 1932. His training as a geologist began in 1876 in Saxony, where Werner, one of the fathers of geology, and afterwards a great number of eminent mineralogists and geologists, from Von Humboldt, Von Buch, Breithaupt, Mohs, and Naumann to Brush, Pumpelly, Emmons, Hague, and Lindgren, studied or taught. In 1880 Vogt won the degree of mining engineer at Oslo and then, at the universities of Stockholm and Paris, further prepared himself for leadership. At the age of twenty-eight he was appointed a professor at the University of Oslo, whence, in 1912, he went to the Technological Institute at Trondhjem as Professor of Geology and Metallurgy. From this position he retired in 1929.

In order to secure first-hand knowledge of the facts relating to his intricate subject, Vogt visited mines and mineral deposits all over Scandinavia and in most of the other countries of Europe. He enriched such experience by field work for the Geological Survey of Norway. But he saw that solutions to his many problems of origin could not be found in field observations taken alone; he early concluded that experiment could throw a flood of light on his great subject. With remarkable insight he used the precise, quantitative data derived from the slags of metallurgical establishments to discover the physico-chemical laws controlling the voluminous silicate melts or magmas from which oxide, sulphide, and other ore bodies in Nature have been derived. His many monographs detailing his results illustrate his passion for accuracy in observation and reasoning, and will long remain classics in the science of rocks. The number of his published writings totals more than two hundred.

Vogt's power and high achievement were specially recognized by many scientific institutions. He was given an honorary doctor's degree by the Institute of Technology at Aachen. He was elected a member in each of the scientific academies of Oslo, Trondhjem,

Stockholm, Copenhagen, Leningrad, Germany (Deutsche Akademie der Naturforscher), as well as our own Academy of Arts and Sciences. He became honorary member of the Geological Society of London and of the Geological Society of America—each election representing a rare distinction. In 1929 the American Society of Economic Geologists voted him their Penrose gold medal, which is awarded only to first-rank masters in the field of ore deposits. These were some of the honors that came to our colleague and fellow member.

REGINALD A. DALY.

WILLIAM HULTZ WALKER (1869–1934).

Fellow in Class I, Section 3, 1907.

William H. Walker died of a heart attack on July 9, 1934 while driving his car from Bridgton, Maine, to Boston. His loss is a severe blow to the host of men whom he helped and guided during his active life as an educator, an executive, a chemist, and an engineer.

As an educator, he pioneered both in the laying of the foundations for chemical engineering and in the development of the education of chemical engineers. His students will remember best his wonderful friendliness, his insistence upon the value of initiative and personality, and on accuracy and vigor in the presentation of ideas, as well as scientific attainment. Above all, he insisted that conclusions must be based upon factual evidence and that no work is complete until the phenomena involved are so fully understood that the separate variables stand out by themselves and the whole picture can be explained in simple, concise language.

Dr. Walker was born at Pittsburgh, Pennsylvania, the son of David H. and Anna Blair Walker, on April 7, 1869. After graduating from the Pennsylvania State College, he took his doctor's degree in chemistry at the University of Goettingen. In 1894 he taught analytical chemistry at the Massachusetts Institute of Technology.

In 1900 he joined in partnership with Dr. Arthur D. Little to carry on the application of chemistry and physics to industry. In spite of the success which attended the partnership, Dr. Walker could not refuse the call of education and in a few years returned to teaching at the Massachusetts Institute of Technology. He felt that, although needing men well grounded in chemistry and in engineering, chemical

engineering was a profession in itself. He insisted that the demand of industry for men trained to accomplish what the existing staffs of process-industry had not yet been able to do, could not adequately be met by teaching a little engineering to chemists or a little chemistry to mechanical engineers.

Throughout he believed that an educator of engineers should have constant everyday contacts with the industries which his students were to serve. In 1906 he was appointed a special lecturer on industrial chemistry at Harvard University. Here he developed a course along his own ideas and, though he found that the demands on his time were too great to let him continue with it, the few years that he gave to this course attracted many men who later studied chemical engineering.

In 1915, he felt with Dr. Little that the development of chemical engineering necessitated the training of more men equipped for specialized research in this field. With the aid of Dr. Little, there was obtained for Technology from Mr. George Eastman an endowment which permitted him to organize, as a corollary to the teaching of chemical engineering, the Graduate School of Chemical Engineering Practice at the Institute. This same point of view had previously led to the establishment of the Research Laboratory of Applied Chemistry. This Laboratory was so successful that it obtained from its industrial contacts the funds with which to support many of the "*pro bono publico*" researches for the development of some of the fundamental laws of chemical engineering. It has contributed to the knowledge of the mechanisms of the corrosion of iron and steel; contributions which, invaluable as they are to society, are a monument to Walker. These efforts brought chemical engineering to a point where in 1923, in collaboration with two of his former students, Warren K. Lewis and William H. MacAdams, he wrote an outstanding pioneering book of the profession, "The Principles of Chemical Engineering."

Almost at the start of this country's entrance into the World War, he was called to Washington to help with various problems incident to chemical warfare. As Colonel in the Chemical Warfare Service, he was placed first in charge of the completion and organization of Edgewood Arsenal and later of the entire Gas Offense Division of the Chemical Warfare Service. The organization which he took over was badly disrupted by the petty jealousies and uncertainties incident to

reorganizations and the making of a full fledged service from what had been at the start an "orphan child" of the Ordinance Department. The difficulties which he encountered and surmounted and his successes are a chapter in themselves. When he left the Service at the end of the War, the Distinguished Service Medal, which he received for his achievements, had been obtained at the expense of irreparable damage to his constitution.

In the spring of 1919 he returned to the Massachusetts Institute of Technology full of plans and hopes for the further development of the Department of Chemical Engineering, the School of Chemical Engineering Practice, and the Research Laboratory of Industrial Chemistry, all three of which he headed. However, his enjoyment of this prospect was but short-lived. In January of the next year he was persuaded by President MacLaurin to undertake as a labor of love for the Institute the work of financing and organizing the Division of Industrial Cooperation and Research. Upon the death of President MacLaurin he was made a member of the Administrative Committee of the Institute but, as his health was impaired, he soon retired with the thought that he would lead a comparatively inactive life and carry on but a desultory specialized consulting practice. However, he no sooner had recovered from a severe operation and regained his health than he was swamped by demands upon his time. Up to the very end, he was active as a consultant, often in connection with large patent litigations, where his keen and analytic reasoning allowed him to present complex situations, but little understood by many technical men, so clearly that they were readily understood by laymen and jurists.

He was identified with many scientific organizations and contributed frequently to the scientific literature. He was Vice-President of the International Congress of Applied Chemistry in Berlin in 1893, was President of the Electro-Chemical Society in 1910, and was awarded the Nichols Medal in 1908. He was also an active member of the Committee of the American Chemical Society to cooperate with the Chemical Warfare Service, a non-resident professor of chemical engineering, a member of the Visiting Committee of the Department of Chemical Engineering at the Massachusetts Institute of Technology, and a director of Dewey and Almy Chemical Company.

Of late years he maintained a winter home in Pasadena, California,

and a summer residence at Bridgton, Maine. He is survived by his widow, Isabelle Luther Walker, and his son, Jonathan L. Walker, of Los Angeles.

BRADLEY DEWEY.¹

ROBERT DE COURCY WARD (1867-1931).

Fellow in Class II, Section 1, 1898.

Many years ago there was a meeting of a certain Club at the home of Professor and Mrs. Robert De Courcy Ward in Cambridge. After some routine matters had been disposed of, the host, as essayist of the evening, read a paper on Climate in the Eastern part of the United States and its effect on personal character. The paper had been carefully prepared and the speaker was listened to with interest. When it was finished and discussion was in order, one of the company arose and after stating his own views at considerable length proceeded to criticize the figures given and whether he meant it or not, his remarks were unfavorable to Professor Ward. The group sat in mute astonishment. Then the writer rose and perhaps with more heat than was necessary proceeded to prove that the figures were authentic, that the second speaker was in dense ignorance of certain matters, and that Professor Ward was the leading climatologist in our country. For a long time after the meeting, comments of a congratulatory nature reached him. Ward was then just coming into prominence for his researches in climatic matters. Climatology was indeed his first and chief vocation. He had many classes at Harvard and his lectures upheld the high scholarship of his predecessor Professor William M. Davis. He had served as Assistant for many years, some of the time without pay, and one might note much of the ways and methods of the earlier instructor in his lectures. Outside the lecture room there stood a large case filled with carefully indexed copies of the various papers sent to him from all parts of the world. Once when looking over the case, and somewhat regretful of the time he had been forced to spend on it, he offered to bequeath it to the writer; but only to have the generous offer declined for the simple reason that the writer was himself overburdened with like matter.

¹ Slightly condensed from a notice in *Nucleus*, N. E. Sect. Amer. Chem. Soc., Nov. 1934.

The number of papers that Ward handled was tremendous. And he was familiar with the contents of each one. Some of his classes were very large and in later years he required several assistants. He was a competent instructor, speaking clearly and easily. It was evident that he knew whereof he was talking. He also had some classes at Radcliffe.

The Control of Immigration was his avocation and he wrote and spoke concerning the character of immigrants and the need of limiting the quotas. In this he was successful and his views were appreciated and acted upon by those in authority.

At the College, he was one of the prominent members of the Committee on Instruction and later on Admission. He seldom missed any of the meetings, and this work required much time. He was careful in scrutinizing the work of candidates and never hesitated to express his views on the various matters that would arise. He held the chair of Climatology at Harvard for twenty-one years. In his earlier days he was Editor of the American Meteorological Magazine, one of the contributing Editors of the Geographical Magazine (continued until his death) and one of the writers on the Encyclopedia Britannica. He was the author of several books, the best known of which are "Climate in Relation to Man" and the "Climates of the United States." His translation of Hann's work is also widely known. He was a member of the American Academy of Arts and Sciences, the Royal Meteorological Society, the Association of American Geographers, the American Philosophical Society, the American Geographical Society and other learned bodies.

He married Miss Emma Lane of St. Louis, Missouri, in April 1897 and their home life with four children, two boys and two girls, was most happy. His wife died shortly after his death.

ALEXANDER MCADIE.

American Academy of Arts and Sciences.

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(Corrected to January 14, 1935.)

FELLOWS.—770.

(Numbered limited to eight hundred.)

CLASS I.—*Mathematical and Physical Sciences*.—215.

SECTION I.—*Mathematics and Astronomy*.—55.

Charles Greeley Abbot	Washington, D. C.
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CLASS I., SECTION II.—*Physics*.—63.

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David Elbridge Worrall	Tufts College

CLASS I., SECTION IV.—*Technology and Engineering.*—46.

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Vannevar Bush	Belmont
Harry Ellsworth Clifford	Newton
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Ellsworth Huntington	New Haven, Conn.
Robert Tracy Jackson	Peterborough, N. H.
Thomas Augustus Jaggar	Honolulu, T. H.
Douglas Wilson Johnson	New York, N. Y.
Arthur Keith	Washington, D. C.
Alfred Church Lane	Cambridge
Esper Signius Larsen, Jr.	Cambridge
Andrew Cowper Lawson	Berkeley, Cal.
Charles Kenneth Leith	Madison, Wis.

Waldemar Lindgren	Brookline
Frederic Brewster Loomis	Amherst
Alexander George McAdie	Hampton, Va.
George Francis McEwen	La Jolla, Cal.
Donald Hamilton McLaughlin	Cambridge
Kirtley Fletcher Mather	Cambridge
Edward Bennett Mathews	Baltimore, Md.
John Campbell Merriam	Washington, D. C.
William John Miller	Los Angeles, Cal.
Frederick Kuhne Morris	Cambridge
Walter Harry Newhouse	Cambridge
Charles Palache	Cambridge
Percy Edward Raymond	Lexington
Austin Flint Rogers	Palo Alto, Cal.
Carl-Gustaf Arvid Rossby	Hingham
Robert Wilcox Sayles	Chestnut Hill
Waldemar Theodore Schaller	Washington, D. C.
Charles Schuchert	New Haven, Conn.
William Berryman Scott	Princeton, N. J.
Hervey Woodburn Shimer	Hingham
Frank Bursley Taylor	Fort Wayne, Ind.
Thomas Wayland Vaughan	La Jolla, Cal.
Charles Hyde Warren	New Haven, Conn.
David White	Washington, D. C.
Herbert Percy Whitlock	New York, N. Y.
Bailey Willis	Palo Alto, Cal.
John Eliot Wolff	Pasadena, Cal.
Frederick Eugene Wright	Washington, D. C.

CLASS II., SECTION II.—*Botany*.—37.

LeRoy Abrams	Stanford University, Cal.
Oakes Ames	North Easton
Edgar Anderson	Jamaica Plain
Joseph Charles Arthur	Lafayette, Ind.
Irving Widmer Bailey	Cambridge
Liberty Hyde Bailey	Ithaca, N. Y.
Edward Wilber Berry	Baltimore, Md.
Douglas Houghton Campbell	Palo Alto, Cal.

George Perkins Clinton	New Haven, Conn.
Bradley Moore Davis	Ann Arbor, Mich.
Edward Murray East	Jamaica Plain
Rollins Adams Emerson	Ithaca, N. Y.
Alexander William Evans	New Haven, Conn.
Joseph Horace Faull	Cambridge
Merritt Lyndon Fernald	Cambridge
Robert Almer Harper	New York, N. Y.
Albert Spear Hitchcock	Washington, D. C.
John George Jack	East Walpole
Willis Linn Jepson	Berkeley, Cal.
Ivan Murray Johnston	Brookline
Donald Forsha Jones	New Haven, Conn.
Jacob Goodale Lipman	New Brunswick, N. J.
Burton Edward Livingston	Baltimore, Md.
Elmer Drew Merrill	Berkeley, Cal.
Winthrop John Vanleuven Osterhout	New York, N. Y.
George James Peirce	Palo Alto, Cal.
Alfred Rehder	Jamaica Plain
Benjamin Lincoln Robinson	Cambridge
Karl Sax	Jamaica Plain
William Albert Setchell	Berkeley, Cal.
Edmund Ware Sinnott	New York, N. Y.
Gilbert Morgan Smith	Stanford University, Cal.
Elvin Charles Stakman	St. Paul, Minn.
William Trelease	Urbana, Ill.
Charles Alfred Weatherby	Cambridge
William Henry Weston, Jr.	Cambridge
Ralph Hartley Wetmore	Belmont

CLASS II., SECTION III.—*Zoology and Physiology*.—69.

Nathan Banks	Cambridge
Thomas Barbour	Boston
Philip Bard	Baltimore, Md.
Francis Gano Benedict	Boston
Henry Bryant Bigelow	Concord
Robert Payne Bigelow	Brookline
William T. Bovie	Bar Harbor, Me.

Edward Allen Boyden	Minneapolis, Minn.
John Lewis Bremer	Boston
Charles Thomas Brues	Jamaica Plain
John Wymond Miller Bunker	Belmont
Walter Bradford Cannon	Cambridge
Thorne Martin Carpenter	Boston
William Ernest Castle	Belmont
Charles Value Chapin	Providence, R. I.
Lemuel Roscoe Cleveland	Jamaica Plain
Edwin Joseph Cohn	Cambridge
Edwin Grant Conklin	Princeton, N. J.
Manton Copeland	Brunswick, Me.
William John Crozier	Cambridge
Joseph Augustine Cushman	Sharon
Charles Benedict Davenport	Cold Spring Harbor, N. Y.
Hallowell Davis	Belmont
Alden Benjamin Dawson	Cambridge
Samuel Randall Detwiler	New York, N. Y.
Herbert McLean Evans	Berkeley, Cal.
Henry Clinton Fall	Tyngsboro
Cyrus Hartwell Fiske	Belmont
Alexander Forbes	Milton
John Farquhar Fulton	New Haven, Conn.
William King Gregory	New York, N. Y.
Joseph Grinnell	Berkeley, Cal.
Samuel Henshaw	Cambridge
Leigh Hoadley	Cambridge
Hudson Hoagland	Worcester
Samuel Jackson Holmes	Berkeley, Cal.
Roy Graham Hoskins	Newton Center
Leland Ossian Howard	Washington, D. C.
Herbert Spencer Jennings	Baltimore, Md.
Charles Atwood Kofoed	Berkeley, Cal.
Frederic Thomas Lewis	Waban
Frank Rattray Lillie	Chicago, Ill.
Ralph Stayner Lillie	Chicago, Ill.
Richard Swann Lull	New Haven, Conn.
Edward Laurens Mark	Cambridge

Albert Davis Mead	Providence, R. I.
Axel Leonard Melander	New York, N. Y.
Gerrit Smith Miller	Washington, D. C.
Thomas Hunt Morgan	Pasadena, Cal.
Herbert Vincent Neal.	Tufts College
Henry Fairfield Osborn	New York, N. Y.
George Howard Parker	Cambridge
Raymond Pearl	Baltimore, Md.
John Charles Phillips	Wenham
Henry Augustus Pilsbry	Philadelphia, Pa.
Frederick Haven Pratt	Wellesley Hills
Herbert Wilbur Rand	Cambridge
David Rapport	Cambridge
Alfred Clarence Redfield	Milton
Alfred Newton Richards	Philadelphia, Pa.
Oscar Riddle	Cold Spring Harbor, N. Y.
William Emerson Ritter	Berkeley, Cal.
Alexander Grant Ruthven	Ann Arbor, Mich.
Percy Goldthwait Stiles	Newtonville
Arthur Wisswald Weyssse	Boston
William Morton Wheeler.	Boston
Edmund Beecher Wilson.	New York, N. Y.
Frederick Adams Woods.	Rome, Italy
Jeffries Wyman, Jr.	Chestnut Hill

CLASS II., SECTION IV.—*Medicine and Surgery*.—55.

Joseph Charles Aub	Belmont
James Bourne Ayer	Milton
Franklin Greene Balch	Boston
George Blumer	New Haven, Conn.
Charles Macfie Campbell	Cambridge
Alexis Carrel	New York, N. Y.
William Bosworth Castle	Boston
David Cheever.	Boston
Henry Asbury Christian	Boston
Rufus Cole.	New York, N. Y.
Harvey Cushing	New Haven, Conn.
Elliott Carr Cutler	Brookline

Eugene Floyd DuBois	New York, N. Y.
Reginald Fitz	Brookline
Simon Flexner	New York, N. Y.
James Lawder Gamble	Brookline
Joseph Lincoln Goodale	Boston
Robert Battey Greenough	Boston
Ross Granville Harrison	New Haven, Conn.
Percy Rogers Howe	Belmont
William Henry Howell	Baltimore, Md.
Edgar Erskine Hume	Washington, D. C.
Reid Hunt	Boston
Henry Jackson, Jr.	Chestnut Hill
Elliott Proctor Joslin	Boston
Roger Irving Lee	Brookline
Edwin Allen Locke	Boston
Warfield Theobald Longcope	Baltimore, Md.
Fred Bates Lund	Newton
George Burgess Magrath	Boston
Frank Burr Mallory	Brookline
William James Mayo	Rochester, Minn.
Leroy Matthew Simpson Miner	Newtonville
George Richards Minot	Brookline
William Lorenzo Moss	Augusta, Ga.
John Howard Mueller	Boston
Robert Bayley Osgood	Boston
Joseph Hershey Pratt	Boston
William Carter Quinby	Brookline
Milton Joseph Rosenau	Brookline
Arthur Hiler Ruggles	Providence, R. I.
Andrew Watson Sellards	Boston
George Cheever Shattuck	Brookline
Torald Hermann Sollmann	Cleveland, Ohio
Charles Wardell Stiles	Washington, D. C.
Richard Pearson Strong	Boston
Fritz Bradley Talbot	Brookline
Ernest Edward Tyzzer	Wakefield
Frederick Herman Verhoeff	Boston
Joseph Treloar Wearn	Cleveland, Ohio

Soma Weiss	Cambridge
Benjamin White	New York, N. Y.
Francis Henry Williams	Boston
Simeon Burt Wolbach	Sudbury
Hans Zinsser	Boston

CLASS III.—*The Social Arts*.—139.SECTION I.—*Jurisprudence*.—34.

George Weston Anderson	Boston
Francis Noyes Balch	Jamaica Plain
Joseph Henry Beale	Cambridge
Harry Augustus Bigelow	Chicago, Ill.
Henry Wolf Biklé	Philadelphia, Pa.
Benjamin Nathan Cardozo	Washington, D. C.
John Dickinson	Washington, D. C.
Fred Tarbell Field	Newton
Felix Frankfurter	Cambridge
Thomas Hovey Gage	Worcester
Theodore Francis Green	Providence, R. I.
Walter Perley Hall	Fitchburg
Learned Hand	New York, N. Y.
Charles Evans Hughes	Washington, D. C.
Nathan Isaacs	Cambridge
Eldon Revare James	Cambridge
Frederick Lawton	Boston
Sayre Macneil	Azusa, Cal.
Calvert Magruder	Cambridge
William DeWitt Mitchell	New York, N. Y.
Edmund Morris Morgan	Arlington
Herbert Parker	South Lancaster
George Wharton Pepper	Philadelphia, Pa.
Roscoe Pound	Watertown
Elihu Root	New York, N. Y.
Arthur Prentice Rugg	Worcester
Francis Bowes Sayre	Washington, D. C.
Austin Wakeman Scott	Cambridge
Harlan Fiske Stone	Washington, D. C.

Edward Sampson Thurston	Cambridge
William Cushing Wait	Medford
Eugene Wambaugh	Cambridge
Edmund Allen Whitman	Cambridge
George Woodward Wickersham	New York, N. Y.

CLASS III., SECTION II.—*Government, International Law, and Diplomacy.*—24.

George Hubbard Blakeslee	Worcester
Edwin Montefiore Borchard	New Haven, Conn.
William Richards Castle, Jr.	Washington, D. C.
Joseph Perkins Chamberlain	New York, N. Y.
Robert Treat Crane	New York, N. Y.
Sidney Bradshaw Fay	Cambridge
William Cameron Forbes	Norwood
Edgar Stephenson Furniss	New Haven, Conn.
Joseph Clark Grew	Tokyo, Japan
Albert Bushnell Hart	Cambridge
Arthur Norman Holcombe	Cambridge
Manley Ottmer Hudson	Cambridge
Philip Carryl Jessup	New York, N. Y.
Abbott Lawrence Lowell	Boston
William MacDonald	New York, N. Y.
Charles Edward Merriam	Chicago, Ill.
Ogden Livingston Mills	New York, N. Y.
John Bassett Moore	New York, N. Y.
William Bennett Munro	Pasadena, Cal.
Westal Woodbury Willoughby	Washington, D. C.
William Franklin Willoughby	Washington, D. C.
George Grafton Wilson	Cambridge
Quincy Wright	Chicago, Ill.
Henry Aaron Yeomans	Cambridge

CLASS III., SECTION III.—*Economics and Sociology.*—53.

Charles Jesse Bullock	Cambridge
Harold Hitchings Burbank	Cambridge
Richard Clarke Cabot	Cambridge
Thomas Nixon Carver	Cambridge
John Bates Clark	New York, N. Y.

John Maurice Clark	Westport, Conn.
Arthur Harrison Cole.	Cambridge
Melvin Thomas Copeland	Cambridge
William Leonard Crum	Cambridge
William James Cunningham.	Cambridge
Winthrop More Daniels	New Haven, Conn.
Clive Day	New Haven, Conn.
Davis Rich Dewey	Cambridge
Arthur Stone Dewing.	Newton
Wallace Brett Donham	Boston
John Franklin Ebersole	Belmont
Irving Fisher	New Haven, Conn.
James Ford	Cambridge
Ralph Evans Freeman	Cambridge
Edwin Francis Gay	Cambridge
Sheldon Glueck	Cambridge
Robert Murray Haig	New York, N. Y.
Henry Wyman Holmes	Cambridge
Edwin Walter Kemmerer	Princeton, N. J.
Frank Hyneman Knight	Chicago, Ill.
Robert Morison MacIver	New York, N. Y.
Walter Wallace McLaren	Williamstown
Leon Carroll Marshall	Washington, D. C.
Edward Sagendorph Mason	Cambridge
Richard Stockton Meriam	South Lincoln
Harry Alvin Millis	Washington, D. C.
Frederick Cecil Mills	New York, N. Y.
Wesley Clair Mitchell	New York, N. Y.
Arthur Eli Monroe	Cambridge
Harold Glenn Moulton	Washington, D. C.
Edwin Griswold Nourse	Washington, D. C.
William Fielding Ogburn.	Chicago, Ill.
Robert Ezra Park.	Chicago, Ill.
Warren Milton Persons	New York, N. Y.
Leo S. Rowe	Washington, D. C.
Josef Alois Schumpeter	Cambridge
Carl Snyder	New York, N. Y.
Pitirim Alexandrovich Sorokin	Winchester

Oliver Mitchell Wentworth Sprague	Cambridge
Frank William Taussig	Cambridge
Frederick John Teggart	Berkeley, Cal.
William Isaac Thomas	New York, N. Y.
Donald Skeelee Tucker	Cambridge
Abbott Payson Usher	Belmont
Jacob Viner	Washington, D. C.
John Henry Williams	Cambridge
Leo Wolman	Washington, D. C.
Carle Clark Zimmerman	Winchester

CLASS III., SECTION IV.—*Administration and Affairs.*—28.

Charles Francis Adams	Concord
Charles Foster Batchelder	Cambridge
George Hoyt Bigelow	Milton
Ingersoll Bowditch	Jamaica Plain
John Albert Cousens	Tufts College
Henry Sturgis Dennison	Framingham
William Lusk Webster Field	Milton
Frank Johnson Goodnow	Baltimore, Md.
Francis Russell Hart	Boston
Edward Jackson Holmes	Boston
Matt Bushnell Jones	Newton Center
Henry Plimpton Kendall	Walpole
Nathaniel Thayer Kidder	Milton
Thomas William Lamont	New York, N. Y.
Clarence Cook Little	Bar Harbor, Me.
James Vance May	Boston
Thomas Nelson Perkins	Westwood
Andrew James Peters	Jamaica Plain
Herbert Putnam	Washington, D. C.
Alfred Lawrence Ripley	Andover
Erwin Haskell Schell	Cambridge
Jeremiah Smith, Jr.	Cambridge
Payson Smith	Brookline
Albert Warren Stearns	Billerica
Charles Henry Taylor	Boston
Charles Franklin Thwing	Cleveland, O.

Edwin Sibley Webster	Brookline
Benjamin Loring Young	Weston

CLASS IV.—*The Humanities*.—202.SECTION I.—*Theology, Philosophy, and Psychology*.—47.

Michael Joseph Ahern	Weston
Gordon Willard Allport	Cambridge
James Rowland Angell	New Haven, Conn.
John Gilbert Beebe-Center	Swampscott
Edwin Garrigues Boring	Cambridge
Edgar Sheffield Brightman	Newton
Henry Addington Bruce	Cambridge
Leonard Carmichael	Providence, R. I.
J(ames) McKeen Cattell	Garrison, N. Y.
George Croft Cell	Reading
Walter Fenno Dearborn	Cambridge
Edmund Burke Delabarre	Providence, R. I.
Raymond Dodge	New Haven, Conn.
Curt John Ducasse	Providence, R. I.
William Henry Paine Hatch	Cambridge
William Healy	Boston
William Arthur Heidel	Middletown, Conn.
William Ernest Hocking	Cambridge
Walter Samuel Hunter	Worcester
Frederick John Foakes Jackson	Englewood, N. J.
Truman Lee Kelley	Cambridge
Albert Cornelius Knudson	Cambridge
Kurt Koffka	Northampton
Karl Spencer Lashley	Chicago, Ill.
William Lawrence	Boston
Clarence Irving Lewis	Cambridge
Lee Sullivan McColleston	Tufts College
William McDougall	Durham, N. C.
Edward Caldwell Moore	Cambridge
Paul Elmer More	Princeton, N. J.
Arthur Darby Nock	Cambridge
William Cardinal O'Connell	Boston

Johnson O'Connor	Boston
Charles Edwards Park	Boston
Leighton Parks	London, England
Francis Greenwood Peabody	Cambridge
Carroll Cornelius Pratt	Cambridge
James Hugh Ryan	Washington, D. C.
Henry Knox Sherrill	Boston
Willard Learoyd Sperry	Cambridge
Russell Henry Stafford	Brookline
Lewis Madison Terman	Stanford University, Cal.
Edward Lee Thorndike	New York, N. Y.
Henry Bradford Washburn	Cambridge
John Broadus Watson	New York, N. Y.
Frederic Lyman Wells	Newton Highlands
Robert Mearns Yerkes	New Haven, Conn.

CLASS IV., SECTION II.—*History, Archaeology, and Anthropology*.—43.

Charles McLean Andrews	New Haven, Conn.
James Phinney Baxter, 3d	Cambridge
Carl Lotus Becker	Ithaca, N. Y.
Robert Pierpont Blake	Cambridge
Franz Boas	New York, N. Y.
William Brooks Cabot	Boston
Clarence Gordon Campbell	New York, N. Y.
George Henry Chase	Cambridge
Wilberforce Eames	New York, N. Y.
Ephraim Emerton	Cambridge
Max Farrand	San Marino, Cal.
William Scott Ferguson	Cambridge
Worthington Chauncey Ford	Cambridge
Henry Thatcher Fowler	Providence, R. I.
Evarts Boutell Greene	New York, N. Y.
Charles Homer Haskins	Cambridge
Charles Downer Hazen	New York, N. Y.
Bert Hodge Hill	Athens, Greece
Earnest Albert Hooton	Cambridge
Halford Lancaster Hoskins	Tufts College
Aleš Hrdlička	Washington, D. C.

Alfred Vincent Kidder	Washington, D. C.
Alfred Louis Kroeber	Berkeley, Cal.
Kirsopp Lake	Cambridge
George LaPiana	Cambridge
Waldo Gifford Leland	Washington, D. C.
Charles Howard McIlwain	Cambridge
Roger Bigelow Merriman	Cambridge
Samuel Eliot Morison	Boston
Robert Henry Pfeiffer	Cambridge
George Andrew Reisner	Boston
David Moore Robinson	Baltimore, Md.
Michael Ivanovich Rostovtzeff	New Haven, Conn.
Edward Sapir	New Haven, Conn.
George Sarton	Cambridge
Theodore Leslie Shear	Princeton, N. J.
Herbert Joseph Spinden	Brooklyn, N. Y.
John Osborne Sumner	Boston
Charles Holt Taylor	Cambridge
Charles Cutler Torrey	New Haven, Conn.
Alfred Marston Tozzer	Cambridge
Clark Wissler	New York, N. Y.
Lawrence Counselman Wroth	Providence, R. I.

CLASS IV., SECTION III.—*Philology*.—56.

Edward Cooke Armstrong	Princeton, N. J.
William Nickerson Bates	Philadelphia, Pa.
Campbell Bonner	Ann Arbor, Mich.
Carleton Brown	New York, N. Y.
Carl Darling Buck	Chicago, Ill.
Edward Capps	Princeton, N. J.
Walter Eugene Clark	Cambridge
Ronald Salmon Crane	Chicago, Ill.
Morris William Croll	Princeton, N. J.
Samuel Hazzard Cross	Cambridge
Franklin Edgerton	New Haven, Conn.
Frank Edgar Farley	Middletown, Conn.
Jeremiah Denis Mathias Ford	Cambridge
James Geddes, Jr.	Brookline

Charles Hall Grandgent	Cambridge
Louis Herbert Gray	New York, N. Y.
William Chase Greene	Cambridge
Charles Burton Gulick	Cambridge
Roy Kenneth Hack	Cincinnati, Ohio
Austin Morris Harmon	New Haven, Conn.
Raymond Dexter Havens	Baltimore, Md.
George Lincoln Hendrickson	New Haven, Conn.
William Guild Howard	Cambridge
Eugene Xavier Louis Henry Hyvernati	Washington, D. C.
Carl Newell Jackson	Cambridge
James Richard Jewett	Cambridge
(Ralph) Hayward Keniston	Chicago, Ill.
Roland Grubb Kent	Philadelphia, Pa.
George Lyman Kittredge	Cambridge
Hans Kurath	Providence, R. I.
Henry Roseman Lang	New Haven, Conn.
Ernest Felix Langley	Cambridge
Charles Rockwell Lanman	Cambridge
Ivan Mortimer Linforth	Berkeley, Cal.
David Gordon Lyon	Cambridge
Francis Peabody Magoun, Jr.	Cambridge
Albert Matthews	Boston
William Albert Nitze	Chicago, Ill.
George Rapall Noyes	Berkeley, Cal.
William Abbott Oldfather	Urbana, Ill.
Milman Parry	Belmont
Howard Rollin Patch	Northampton
Arthur Stanley Pease	Cambridge
Edward Kennard Rand	Cambridge
Fred Norris Robinson	Cambridge
Robert Kilburn Root	Princeton, N. J.
Rudolph Schevill	Berkeley, Cal.
Horatio Elwin Smith	Providence, R. I.
Herbert Weir Smyth	Cambridge
Franklin Bache Stephenson	Washington, D. C.
William Thomson	Cambridge
George Benson Weston	Cambridge

Joshua Whatmough	Cambridge
Ernest Hatch Wilkins	Oberlin, Ohio
Harry Austryn Wolfson	Cambridge
Karl Young	New Haven, Conn.

CLASS IV., SECTION IV.—*The Fine Arts and Belles Lettres*.—56.

Stephen Vincent Benét	New York, N. Y.
Frank Weston Benson	Salem
(William) Welles Bosworth	New York, N. Y.
John Alden Carpenter	Chicago, Ill.
Chalmers Dancy Clifton	New York, N. Y.
Charles Collens	Newton Center
Kenneth John Conant	Cambridge
Charles Jay Connick	Newtonville
Frederick Shepherd Converse	Westwood
Charles Allerton Coolidge	Boston
Charles Townsend Copeland	Cambridge
Ralph Adams Cram	Boston
Cyrus Edwin Dallin	Arlington Heights
Samuel Foster Damon	Providence, R. I.
George Harold Edgell	Cambridge
William Emerson	Cambridge
Carl Engel	Washington, D. C.
John Erskine	New York, N. Y.
Arthur Fairbanks	Hanover, N. H.
Edward Waldo Forbes	Cambridge
Robert Frost	South Shaftsbury, Vt.
Wallace Goodrich	Boston
Robert Grant	Boston
Chester Noyes Greenough	Cambridge
Edward Burlingame Hill	Boston
Robert Silliman Hillyer	Cambridge
Charles Hopkinson	Manchester
Mark Antony DeWolfe Howe	Boston
Archer Milton Huntington	New York, N. Y.
Henry James	New York, N. Y.
William James	Cambridge
Leo Rich Lewis	Tufts College

John Ellerton Lodge	Washington, D. C.
Charles Martin Tornov Loeffler.	Medfield
John Livingston Lowes	Cambridge
Charles Donagh Maginnis	Brookline
Paul Manship	New York, N. Y.
Daniel Gregory Mason	New York, N. Y.
Frank Jewett Mather	Washington Crossing, Pa.
Kenneth Ballard Murdock	Cambridge
William Allan Neilson	Northampton
Curtis Hidden Page	Gilmanton, N. H.
William Lyon Phelps	New Haven, Conn.
Anthony John Philpott	Arlington
Chandler Rathfon Post	Cambridge
Edwin Arlington Robinson	New York, N. Y.
Denman Waldo Ross	Cambridge
Paul Joseph Sachs	Cambridge
Ellery Sedgwick	Boston
Henry Dwight Sedgwick	Dedham
Henry Richardson Shepley	Brookline
David Stanley Smith.	Woodbridge, Conn.
Edmund C. Tarbell	New Castle, N. H.
Charles Howard Walker	Boston
Owen Wister	Philadelphia, Pa.
Charles Henry Conrad Wright	Cambridge

FOREIGN HONORARY MEMBERS.—121.

(Number limited to one hundred and thirty.)

CLASS I.—*Mathematical and Physical Sciences*.—34.SECTION I.—*Mathematics and Astronomy*.—9.

Arthur Stanley Eddington	Cambridge, England
Ronald Aylmer Fisher	Harpenden, Herts
Jacques Salomon Hadamard.	Paris
Godfrey Harold Hardy	Cambridge, England
Ejnar Hertzsprung	Leyden
Tullio Levi-Civita.	Rome
Charles Emile Picard.	Paris
Charles Jean de la Vallée Poussin	Louvain
Hermann Weyl	Princeton, N. J.

CLASS I., SECTION II.—*Physics*.—9.

Vilhelm Frimann Koren Bjerknes	Oslo
Albert Einstein	Princeton, N. J.
James Franck	Copenhagen
Abram F. Joffé	Leningrad
Sir Joseph Larmor	Cambridge, England
Friedrich Paschen.	Charlottenburg
Max Planck	Berlin
Ernest Rutherford, Baron Rutherford	Cambridge, England
Sir Joseph John Thomson	Cambridge, England

CLASS I., SECTION III.—*Chemistry*.—8.

Johannes N. Brönsted	Copenhagen
Peter Debye	Leipzig
Jaroslav Heyrovsky	Prague
Henri Louis Le Chatelier	Paris
Fritz Paneth	London
Sören Peter Lauritz Sörensen	Copenhagen
Heinrich Wieland	Munich
Richard Willstätter	Munich

CLASS I., SECTION IV.—*Technology and Engineering*.—8.

Paul Janet	Paris
Luigi Lombardi	Rome
Maurice d'Ocagne.	Paris
Ludwig Prandtl	Göttingen
Emil Probst	Karlsruhe
Aurel Stodola	Zürich
Vsevolod Evgenievich Timonoff.	Leningrad
Karl Willy Wagner	Berlin

CLASS II.—*Natural and Physiological Sciences*.—32.SECTION I.—*Geology, Mineralogy, and Physics of the Globe*.—9.

Frank Dawson Adams	Montreal
Charles Barrois	Lille
Waldemar Christofer Brögger	Oslo
Léon William Collet	Geneva
Albert Heim	Zürich
Arthur Holmes	Durham
Emmanuel de Margerie	Paris
Gustaf Adolf Frederik Molengraaff	Delft
Sir William Napier Shaw	London

CLASS II., SECTION II.—*Botany*.—7.

Frederick Orpen Bower	Ripon
Ludwig Diels	Berlin
Kingo Miyabe.	Sapporo, Japan
Alfred Barton Rendle	Leatherhead, Surrey, England
Otto Renner	Jena
Albert Charles Seward	Cambridge, England
Hugo de Vries	Luntern

CLASS II., SECTION III.—*Zoology and Physiology*.—9.

George Albert Boulenger	Brussels
Maurice Caullery	Paris
Archibald Vivian Hill	London
August Krogh	Copenhagen
Louis Édouard Lapicque.	Paris

George Henry Falkiner Nuttall	Cambridge, England
Charles Tate Regan	London
Hans Spemann	Freiburg i. Br.
D'Arcy Wentworth Thompson	St. Andrews

CLASS II., SECTION IV.—*Medicine and Surgery*.—7.

Sir Thomas Barlow, Bart.	London
Sir Henry Hallett Dale	London
Sir Arthur Keith	London
Mikinosuke Miyajima	Tokyo
Friedrich von Müller	Munich
Sir Charles Scott Sherrington	Oxford
Sir Arnold Theiler	London

CLASS III.—*The Social Arts*.—21.SECTION I.—*Jurisprudence*.—9.

Frantz Dahl	Copenhagen
Léon Duguit	Bordeaux
François Geny	Nancy
Hans Kelsen	Vienna
Juljusz Makarewicz	Lwów
Rt. Hon. Sir Frederick Pollock, Bart.	London
Joseph Redlich	Cambridge, Mass.
Rudolph Stammler	Wernigerode a. H.
Giorgio Del Vecchio	Rome

SECTION II.—*Government, International Law, and Diplomacy*.—2.

Paul Claudel	Paris
Hu Shih	Peiping

SECTION III.—*Economics and Sociology*.—7.

Arthur Lyon Bowley	Harpenden, Herts
Gustav Cassel	Djursholm, Sweden
Ralph George Hawtrey	London
Arthur Cecil Pigou	Cambridge, England
Charles Rist	Fraisses (Loire)
Werner Sombart	Berlin
Peter B. Struve	Belgrade

SECTION IV.—*Administration and Affairs.*—3.

Gösta A. Bagge	Stockholm
Rufus Daniel Isaacs, Marquess of Reading	London
Sir Josiah Stamp	Shortlands, Kent

CLASS IV.—*The Humanities.*—34.SECTION I.—*Theology, Philosophy, and Psychology.*—7.

Henri Louis Bergson	Paris
Francis Crawford Burkitt	Cambridge, England
Benedetto Croce	Naples
Étienne Gilson	Melun
Edmund Husserl	Freiburg i. B.
Pierre Janet	Paris
Wolfgang Köhler	Berlin

SECTION II.—*History, Archæology, and Anthropology.*—10.

Rafael Altamira y Crevea	Madrid
Godfrey Rathbone Benson, Baron Charnwood	Lichfield
Wilhelm Dörpfeld	Berlin-Lichterfelde
Rt. Hon. Herbert Albert Laurens Fisher	Oxford
Friedrich Meinecke	Berlin-Dahlem
Karl Pearson	London
Henri Pirenne	Uccle-Brussels
Sir Aurel Stein	Srinagar, Kashmir
Charles Sanford Terry	Aberdeen
George Macaulay Trevelyan	Cambridge, England

SECTION III.—*Philology.*—8.

Joseph Bédier	Paris
Hermann Georg Jacobi	Bonn
Sylvain Lévi	Paris
Paul Mazon	Paris
Antoine Meillet	Paris
Hanns Oertel	Munich
Ramón Menéndez Pidal	Madrid
Frederick William Thomas	Oxford

SECTION IV.—*The Fine Arts and Belles Lettres*.—9.

Alfredo Casella	Rome
Henry Guy	Grenoble
Paul Hazard	Paris
Rudyard Kipling	Burwash, Sussex
Serge Koussevitzky	Paris and Boston
Victor Laloux	Paris
Gilbert Murray	Oxford
Edgar Allison Peers	Liverpool
Henri Rabaud	Paris

ALPHABETICAL INDEX TO LISTS OF MEMBERS.

The letters F and FHM refer to the lists of Fellows and Foreign Honorary Members, respectively. The class and section are indicated by the numerals following.

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|----------------------------------|------------------------------|
| Abbot, C. G. F, I: 1 | Barus, C. F, I: 2 |
| Abrams, L. R. F, II: 2 | Batchelder, C. F. F, III: 4 |
| Adams, C. A. F, I: 4 | Bates, W. N. F, IV: 3 |
| Adams, C. F. F, III: 4 | Baxter, G. P. F, I: 3 |
| Adams, C. R. F, I: 1 | Baxter, J. P., 3d. F, IV: 2 |
| Adams, F. D. FHM, II: 1 | Beale, J. H. F, III: 1 |
| Adams, R. F, I: 3 | Beattie, J. A. F, I: 3 |
| Adams, W. S. F, I: 1 | Becker, C. L. F, IV: 2 |
| Agassiz, G. R. F, I: 1 | Bédier, J. FHM, IV: 3 |
| Ahern, M. J. F, IV: 1 | Beebe-Center, J. G. F, IV: 1 |
| Altamira y Crevea, R. FHM, IV: 2 | Benedict, F. G. F, II: 3 |
| Allport, G. W. F, IV: 1 | Benét, S. V. F, IV: 4 |
| Ames, A., Jr. F, I: 2 | Bennett, A. A. F, I: 1 |
| Ames, J. S. F, I: 2 | Benson, F. W. F, IV: 4 |
| Ames, O. F, II: 2 | Bergson, H. L. FHM, IV: 1 |
| Anderson, E. F, II: 2 | Berry, C. H. F, I: 4 |
| Anderson, G. W. F, III: 1 | Berry, E. W. F, II: 2 |
| Andrews, C. M. F, IV: 2 | Bigelow, G. H. F, III: 4 |
| Angell, J. R. F, IV: 1 | Bigelow, H. A. F, III: 1 |
| Archibald, R. C. F, I: 1 | Bigelow, H. B. F, II: 3 |
| Armstrong, E. C. F, IV: 3 | Bigelow, R. P. F, II: 3 |
| Arthur, J. C. F, II: 2 | Biklé, H. W. F, III: 1 |
| Atwood, W. W. F, II: 1 | Birkhoff, G. D. F, I: 1 |
| Aub, J. C. F, II: 4 | Bjerknes, V. F. K. FHM, I: 2 |
| Ayer, J. B. F, II: 4 | Blake, R. P. F, IV: 2 |
| Bagge, G. A. FHM, III: 4 | Blakeslee, G. H. F, III: 2 |
| Bailey, I. W. F, II: 2 | Blanchard, A. A. F, I: 3 |
| Bailey, L. H. F, II: 2 | Blumer, G. F, II: 4 |
| Balch, F. G. F, II: 4 | Boas, F. F, IV: 2 |
| Balch, F. N. F, III: 1 | Bogert, M. T. F, I: 3 |
| Bancroft, W. D. F, I: 3 | Bonner, C. F, IV: 3 |
| Banks, N. F, II: 3 | Borchard, E. M. F, III: 2 |
| Barbour, T. F, II: 3 | Boring, E. G. F, IV: 1 |
| Bard, P. F, II: 3 | Bosworth, W. F, IV: 1 |
| Barlow, Sir T. FHM, II: 4 | Boulenger, G. A. FHM, II: 3 |
| Barnett, S. J. F, I: 2 | Bovie, W. T. F, II: 3 |
| Barrois, C. FHM, II: 1 | Bowditch, I. F, III: 4 |
| Barrows, H. K. F, I: 4 | Bowen, N. L. F, II: 1 |

- Bower, F. O. FHM, II: 2
 Bowley, A. L. FHM, III: 3
 Bowman, I. F, II: 1
 Boyden, E. A. F, II: 3
 Bray, W. C. F, I: 3
 Bremer, J. L. F, II: 3
 Bridgman, P. W. F, I: 2
 Brightman, E. S. F, IV: 1
 Brögger, W. C. FHM, II: 1
 Brönsted, J. N. FHM, I: 3
 Brooks, C. F. F, II: 1
 Brown, C. F, IV: 3
 Brown, E. W. F, I: 1
 Bruce, H. A. F, IV: 1
 Brues, C. T. F, II: 3
 Bryan, K. F, II: 1
 Buck, C. D. F, IV: 3
 Bullock, C. J. F, III: 3
 Bunker, J. W. M. F, II: 3
 Burbank, H. H. F, III: 3
 Burkitt, F. C. FHM, IV: 1
 Burr, W. H. F, I: 4
 Bush, V. F, I: 4
 Byerly, W. E. F, I: 1
 Cabot, R. C. F, III: 3
 Cabot, W. B. F, IV: 2
 Cady, W. G. F, I: 2
 Campbell, C. G. F, IV: 2
 Campbell, C. M. F, II: 4
 Campbell, D. H. F, II: 2
 Campbell, G. A. F, I: 2
 Campbell, L. L. F, I: 2
 Campbell, W. W. F, I: 1
 Cannon, W. B. F, II: 3
 Capps, E. F, IV: 3
 Cardozo, B. N. F, III: 1
 Carmichael, L. F, IV: 1
 Carpenter, F. M. F, II: 1
 Carpenter, J. A. F, IV: 4
 Carpenter, T. M. F, II: 3
 Carrel, A. F, II: 4
 Carver, T. N. F, III: 3
 Casella, A. FHM, IV: 4
 Cassel, G. FHM, III: 3
 Castle, W. B. F, II: 4
 Castle, W. E. F, II: 3
 Castle, W. R., Jr. F, III: 2
 Cattell, J. M. F, IV: 1
 Caullery, M. FHM, II: 3
 Cell, G. C. F, IV: 1
 Chaffee, E. L. F, I: 2
 Chamberlain, J. P. F, III: 2
 Chapin, C. V. F, II: 4
 Charnwood, Lord. FHM, IV: 2
 Chase, G. H. F, IV: 2
 Cheever, D. F, II: 4
 Chittenden, R. H. F, I: 3
 Christian, H. A. F, II: 4
 Clark, J. B. F, III: 3
 Clark, J. M. F, III: 3
 Clark, W. E. F, IV: 3
 Claudel, P. FHM, III: 2
 Clayton, H. H. F, II: 1
 Cleland, H. F. F, II: 1
 Cleveland, L. R. F, II: 3
 Clifford, H. E. F, I: 4
 Clifton, C. D. F, IV: 4
 Clinton, G. P. F, II: 2
 Cohn, E. J. F, II: 3
 Cole, A. H. F, III: 3
 Cole, R. F, II: 4
 Collens, C. F, IV: 4
 Collet, L. W. FHM, II: 1
 Compton, A. H. F, I: 2
 Compton, K. T. F, I: 2
 Comstock, D. F. F, I: 2
 Conant, J. B. F, I: 3
 Conant, K. J. F, IV: 4
 Conklin, E. G. F, II: 3
 Connick, C. J. F, IV: 4
 Converse, F. S. F, IV: 4
 Coolidge, C. A. F, IV: 4
 Coolidge, J. L. F, I: 1
 Coolidge, W. D. F, I: 2
 Copeland, C. T. F, IV: 4
 Copeland, M. F, II: 3
 Copeland, M. T. F, III: 3
 Cousens, J. A. F, III: 4
 Cram, R. A. F, IV: 4
 Crane, R. S. F, IV: 3
 Crane, R. T. F, III: 2
 Crawford, F. H. F, I: 2

- Crew, H. F, I: 2
 Croce, B. FHM, IV: 1
 Croll, M. W. F, IV: 3
 Cross, S. H. F, IV: 3
 Crozier, W. J. F, II: 3
 Crum, W. L. F, III: 3
 Cunningham, W. J. F, III: 3
 Cushing, H. F, II: 4
 Cushman, J. A. F, II: 3
 Cutler, E. C. F, II: 4
 Dahl, F. FHM, III: 1
 Dahl, O. G. C. F, I: 4
 Dale, Sir H. H. FHM, II: 4
 Dallin, C. E. F, IV: 4
 Daly, R. A. F, II: 1
 Damon, S. F. F, IV: 4
 Dana, E. S. F, II: 1
 Daniels, W. M. F, III: 3
 Davenport, C. B. F, II: 3
 Davis, B. M. F, II: 2
 Davis, H. F, II: 3
 Davis, H. N. F, I: 2
 Davis, T. L. F, I: 3
 Davisson, C. J. F, I: 2
 Dawes, C. L. F, I: 4
 Dawson, A. B. F, II: 3
 Day, A. L. F, I: 2
 Day, C. F, III: 3
 Dearborn, W. F. F, IV: 1
 Debye, P. FHM, I: 3
 Delabarre, E. B. F, IV: 1
 Den Hartog, J. P. F, I: 4
 Dennison, H. S. F, III: 4
 Detwiler, S. R. F, II: 3
 Dewey, D. R. F, III: 3
 Dewing, A. S. F, III: 3
 Dickinson, J. F, III: 1
 Dickson, L. E. F, I: 1
 Diels, L. FHM, II: 2
 Dillon, T. H. F, I: 4
 Dodge, R. F, IV: 1
 Dörpfeld, W. FHM, IV: 2
 Donham, W. B. F, III: 3
 Douglas, J. F, I: 1
 Drinker, P. F, I: 4
 Drisko, W. J. F, I: 2
 Duane, W. F, I: 2
 Du Bois, E. F. F, II: 4
 Ducasse, C. J. F, IV: 1
 Duff, A. W. F, I: 2
 Duguit, L. FHM, III: 1
 Dunn, G. F, I: 4
 Durand, W. F. F, I: 4
 Eames, W. F, IV: 2
 East, E. M. F, II: 2
 Ebersole, J. F. F, III: 3
 Eddington, A. S. FHM, I: 1
 Edgell, G. H. F, IV: 4
 Edgerton, F. F, IV: 3
 Einstein, A. FHM, I: 2
 Emerson, R. A. F, II: 2
 Emerson, W. F, IV: 4
 Emerton, E. F, IV: 2
 Engel, C. F, IV: 4
 Erskine, J. F, IV: 4
 Evans, A. W. F, II: 2
 Evans, G. C. F, I: 1
 Evans, H. M. F, II: 3
 Ewell, A. W. F, I: 2
 Fair, G. M. F, I: 4
 Fairbanks, A. F, IV: 4
 Fall, H. C. F, II: 3
 Farley, F. E. F, IV: 3
 Farrand, M. F, IV: 2
 Faull, J. H. F, II: 2
 Fay, F. H. F, I: 4
 Fay, H. F, I: 3
 Fay, S. B. F, III: 2
 Ferguson, W. S. F, IV: 2
 Fergusson, S. P. F, II: 1
 Fernald, M. L. F, II: 2
 Field, F. T. F, III: 1
 Field, W. L. W. F, III: 4
 Fieser, L. F. F, I: 3
 Fisher, H. A. L. FHM, IV: 2
 Fisher, I. F, III: 3
 Fisher, R. A. FHM, I: 1
 Fiske, C. H. F, II: 3
 Fitz, R. F, II: 4
 Flexner, S. F, II: 4
 Forbes, A. F, II: 3
 Forbes, E. W. F, IV: 4

- Forbes, G. S. F, I: 3
 Forbes, W. C. F, III: 2
 Ford, J. F, III: 3
 Ford, J. D. M. F, IV: 3
 Ford, W. C. F, IV: 2
 Ford, W. E. F, II: 1
 Fowler, H. T. F, IV: 2
 Fox, P. F, I: 1
 Franck, J. FHM, I: 2
 Frankfurter, F. F, III: 1
 Franklin, E. C. F, I: 3
 Franklin, F. F, I: 1
 Franklin, P. F, I: 1
 Freeman, R. E. F, III: 3
 Frost, E. B. F, I: 1
 Frost, R. F, IV: 4
 Fulton, J. F. F, II: 3
 Furniss, E. S. F, III: 2
 Gage, T. H. F, III: 1
 Gamble, J. L. F, II: 4
 Gay, E. F. F, III: 3
 Geddes, J., Jr. F, IV: 3
 Geny, F. FHM, III: 1
 Gilboy, G. F, I: 4
 Gillespie, L. J. F, I: 3
 Gilson, E. FHM, IV: 1
 Glueck, S. F, III: 3
 Goldthwait, J. W. F, II: 1
 Goodale, J. L. F, II: 4
 Goodnow, F. J. F, III: 4
 Goodrich, W. F, IV: 4
 Goodwin, H. M. F, I: 2
 Grandgent, C. H. F, IV: 3
 Grant, R. F, IV: 4
 Graton, L. C. F, II: 1
 Graustein, W. C. F, I: 1
 Gray, L. H. F, IV: 3
 Green, T. F. F, III: 1
 Greene, E. B. F, IV: 2
 Greene, W. C. F, IV: 3
 Greenough, C. N. F, IV: 4
 Greenough, R. B. F, II: 4
 Gregory, H. E. F, II: 1
 Gregory, W. K. F, II: 3
 Grew, J. C. F, III: 2
 Grinnell, J. F, II: 3
 Gulick, C. B. F, IV: 3
 Guy, H. FHM, IV: 4
 Hack, R. K. F, IV: 3
 Hadamard, J. S. FHM, I: 1
 Haertlein, A. F, I: 4
 Haig, R. M. F, III: 3
 Hale, G. E. F, I: 2
 Hall, E. H. F, I: 2
 Hall, W. P. F, III: 1
 Hammond, J. H. F, I: 4
 Hand, L. F, III: 1
 Hardy, A. C. F, I: 2
 Hardy, G. H. FHM, I: 1
 Harmon, A. M. F, IV: 3
 Harper, R. A. F, II: 2
 Harrison, G. R. F, I: 2
 Harrison, R. G. F, II: 4
 Hart, A. B. F, III: 2
 Hart, F. R. F, III: 4
 Haskins, C. H. F, IV: 2
 Hatch, W. H. P. F, IV: 1
 Havens, R. D. F, IV: 3
 Hawtrey, R. G. FHM, III: 3
 Hayes, H. V. F, I: 2
 Hazard, P. FHM, IV: 4
 Hazen, C. D. F, IV: 2
 Healy, W. F, IV: 1
 Heidel, W. A. F, IV: 1
 Heim, A. FHM, II: 1
 Henderson, L. J. F, I: 3
 Hendrickson, G. L. F, IV: 3
 Henshaw, S. F, II: 3
 Hertzsprung, E. FHM, I: 1
 Heyrovsky, J. FHM, I: 3
 Hill, A. V. FHM, II: 3
 Hill, B. H. F, IV: 2
 Hill, E. B. F, IV: 4
 Hille, E. F, I: 1
 Hillyer, R. S. F, IV: 4
 Hitchcock, A. S. F, II: 2
 Hitchcock, F. L. F, I: 1
 Hoadley, L. F, II: 3
 Hoagland, H. F, II: 3
 Hocking, W. E. F, IV: 1
 Holcombe, A. N. F, III: 2
 Holmes, A. FHM, II: 1

- Holmes, E. J. F, III: 4
 Holmes, H. W. F, III: 3
 Holmes, S. J. F, II: 3
 Hooton, E. A. F, IV: 2
 Hopkinson, C. F, IV: 4
 Hoskins, H. L. F, IV: 2
 Hoskins, R. G. F, II: 3
 Hovgaard, W. F, I: 4
 Howard, L. O. F, II: 3
 Howard, W. G. F, IV: 3
 Howe, M. A. DeW. F, IV: 4
 Howe, P. R. F, II: 4
 Howell, W. H. F, II: 4
 Hrdlicka, A. F, IV: 2
 Hu Shih. FHM, III: 2
 Hubbard, J. C. F, I: 2
 Hudson, M. O. F, III: 2
 Hughes, C. E. F, III: 1
 Hull, G. F. F, I: 2
 Hume, E. E. F, II: 4
 Humphreys, W. J. F, II: 1
 Hunsaker, J. C. F, I: 4
 Hunt, R. F, II: 4
 Hunter, W. S. F, IV: 1
 Huntington, A. M. F, IV: 4
 Huntington, E. F, II: 1
 Huntington, E. V. F, I: 1
 Hussel, E. FHM, IV: 1
 Hutchins, C. C. F, I: 2
 Hyvernath, E. X. L. H. F, IV: 3
 Isaacs, N. F, III: 1
 Ives, F. E. F, I: 2
 Ives, J. E. F, I: 2
 Jack, J. G. F, II: 2
 Jack, J. R. F, I: 4
 Jackson, C. L. F, I: 3
 Jackson, C. N. F, IV: 3
 Jackson, D. F, I: 1
 Jackson, D. C. F, I: 4
 Jackson, F. J. F. F, IV: 1
 Jackson, H., Jr. F, II: 4
 Jackson, R. T. F, II: 1
 Jacobi, H. G. FHM, IV: 3
 Jaggar, T. A. F, II: 1
 James, E. R. F, III: 1
 James, H. F, IV: 4
 James, W. F, IV: 4
 Janet, Paul. FHM, I: 4
 Janet, Pierre. FHM, IV: 1
 Jennings, H. S. F, II: 3
 Jennings, W. L. F, I: 3
 Jepson, W. L. F, II: 2
 Jessup, P. C. F, III: 2
 Jewett, F. B. F, I: 4
 Jewett, J. R. F, IV: 3
 Joffé, A. F. FHM, I: 2
 Johnson, D. W. F, II: 1
 Johnson, L. J. F, I: 4
 Johnston, I. M. F, II: 2
 Jones, D. F. F, II: 2
 Jones, G. F, I: 3
 Jones, M. B. F, III: 4
 Joslin, E. P. F, II: 4
 Keith, Sir A. FHM, II: 4
 Keith, A. F, II: 1
 Kelley, T. L. F, IV: 1
 Kelsen, H. FHM, III: 1
 Kemble, E. C. F, I: 2
 Kemmerer, E. W. F, III: 3
 Kendall, H. P. F, III: 4
 Keniston, H. F, IV: 3
 Kennelly, A. E. F, I: 4
 Kent, N. A. F, I: 2
 Kent, R. G. F, IV: 3
 Keyes, F. G. F, I: 3
 Kidder, A. V. F, IV: 2
 Kidder, N. T. F, III: 4
 Kipling, R. FHM, IV: 4
 Kistiakowsky, G. B. F, I: 3
 Kittredge, G. L. F, IV: 3
 Knight, F. H. F, III: 3
 Knudson, A. C. F, IV: 1
 Köhler, W. FHM, IV: 1
 Koffka, K. F, IV: 1
 Kofoed, C. A. F, II: 3
 Kohler, E. P. F, I: 3
 Koussevitzky, S. FHM, IV: 4
 Kraus, C. A. F, I: 3
 Kroeber, A. L. F, IV: 2
 Krogh, A. FHM, II: 3
 Kurath, H. F, IV: 3
 Lake, K. F, IV: 2

- Laloux, V. FHM, IV: 4
 Lamb, A. B. F, I: 3
 Lamont, T. W. F, III: 4
 Lampland, C. O. F, I: 1
 Lane, A. C. F, II: 1
 Lang, H. R. F, IV: 3
 Langley, E. F. F, IV: 3
 Langmuir, I. F, I: 3
 Lanman, C. R. F, IV: 3
 La Piana, G. F, IV: 2
 Lapique, L. E. FHM, II: 3
 Larmor, Sir J. FHM, I: 2
 Larsen, E. S. F, II: 1
 Lashley, K. S. F, IV: 1
 Lawrence, R. R. F, I: 4
 Lawrence, W. F, IV: 1
 Lawrence, W. H. F, I: 4
 Laws, F. A. F, I: 2
 Lawson, A. C. F, II: 1
 Lawton, F. F, III: 1
 Le Chatelier, H. L. FHM, I: 3
 Lee, R. I. F, II: 4
 Lefavour, H. F, I: 2
 Leith, C. K. F, II: 1
 Leland, W. G. F, IV: 2
 Lévi, S. FHM, IV: 3
 Levi-Civita, T. FHM, I: 1
 Lewis, C. I. F, IV: 1
 Lewis, F. T. F, II: 3
 Lewis, G. N. F, I: 3
 Lewis, L. R. F, IV: 4
 Lewis, W. K. F, I: 3
 Lillie, F. R. F, II: 3
 Lillie, R. S. F, II: 3
 Lindgren, W. F, II: 1
 Lindsay, R. B. F, I: 2
 Linforth, I. M. F, IV: 3
 Lipman, J. G. F, II: 2
 Little, A. D. F, I: 3
 Little, C. C. F, III: 4
 Livingston, B. E. F, II: 2
 Locke, E. A. F, II: 4
 Lodge, J. E. F, IV: 4
 Loeffler, C. M. T. F, IV: 4
 Lombardi, L. FHM, I: 4
 Longcope, W. T. F, II: 4
 Loomis, F. B. F, II: 1
 Lowell, A. L. F, III: 2
 Lowes, J. L. F, IV: 4
 Lull, R. S. F, II: 3
 Lund, F. B. F, II: 4
 Luyten, W. J. F, I: 1
 Lyman, T. F, I: 2
 Lyon, D. G. F, IV: 3
 McAdie, A. G. F, II: 1
 McColleston, L. S. F, IV: 1
 MacDonald, W. F, III: 2
 McDougall, W. F, IV: 1
 McEwen, G. F. F, II: 1
 Mellwain, C. H. F, IV: 2
 MacInnes, D. A. F, I: 3
 MacIver, R. M. F, III: 3
 McKeehan, L. W. F, I: 2
 McLaren, W. W. F, III: 3
 McLaughlin, D. H. F, II: 1
 Macneil, S. F, III: 1
 Maginnis, C. D. F, IV: 4
 Magoun, F. P., Jr. F, IV: 3
 Magrath, G. B. F, II: 4
 Magruder, C. F, III: 1
 Main, C. T. F, I: 4
 Makarewicz, J. FHM, III: 1
 Mallory, F. B. F, II: 4
 Manship, P. F, IV: 4
 Margerie, E. de. FHM, II: 1
 Mark, E. L. F, II: 3
 Mark, K. L. F, I: 3
 Marks, L. S. F, I: 4
 Marshall, L. C. F, III: 3
 Mason, D. G. F, IV: 4
 Mason, E. S. F, III: 3
 Mather, F. J. F, IV: 4
 Mather, K. F. F, II: 1
 Mathews, E. B. F, II: 1
 Matthews, A. F, IV: 3
 May, J. V. F, III: 4
 Mayo, W. J. F, II: 4
 Mazon, P. FHM, IV: 3
 Mead, A. D. F, II: 3
 Meillet, A. FHM, IV: 3
 Meinecke, F. FHM, IV: 2
 Melander, A. L. F, II: 3

- Mendel, L. B. F, I: 3
 Menzel, D. H. F, I: 1
 Meriam, R. S. F, III: 3
 Merriam, C. E. F, III: 2
 Merriam, J. C. F, II: 1
 Merrill, E. D. F, II: 2
 Merriman, R. B. F, IV: 2
 Merritt, E. G. F, I: 2
 Miller, D. C. F, I: 2
 Miller, G. A. F, I: 1
 Miller, G. S. F, II: 3
 Miller, J. A. F, I: 1
 Miller, W. J. F, II: 1
 Millikan, R. A. F, I: 2
 Millis, H. A. F, III: 3
 Mills, F. C. F, III: 3
 Mills, O. L. F, III: 2
 Mimno, H. R. F, I: 2
 Miner, L. M. S. F, II: 4
 Minot, G. R. F, II: 4
 Mitchell, S. A. F, I: 1
 Mitchell, W. C. F, III: 3
 Mitchell, W. DeW. F, III: 1
 Miyabe, K. FHM, II: 2
 Miyajima, M. FHM, II: 4
 Molengraaff, G. A. F. FHM, II: 1
 Monroe, A. E. F, III: 3
 Moore, E. C. F, IV: 1
 Moore, J. B. F, III: 2
 More, P. E. F, IV: 1
 Moreland, E. L. F, I: 4
 Morgan, E. M. F, III: 1
 Morgan, T. H. F, II: 3
 Morison, S. E. F, IV: 2
 Morley, F. F, I: 1
 Morris, F. K. F, II: 1
 Morse, H. W. F, I: 2
 Morse, M. F, I: 1
 Morse, P. M. F, I: 2
 Moss, W. L. F, II: 4
 Moulton, F. R. F, I: 1
 Moulton, H. G. F, III: 3
 Mueller, E. F, I: 3
 Müller, F. von. FHM, II: 4
 Mueller, J. H. F, II: 4
 Munro, W. B. F, III: 2
 Munroe, C. E. F, I: 3
 Murdock, K. B. F, IV: 4
 Murray, G. FHM, IV: 4
 Neal, H. V. F, II: 3
 Neilson, W. A. F, IV: 4
 Newhouse, W. H. F, II: 1
 Nichols, E. L. F, I: 2
 Nitze, W. A. F, IV: 3
 Nock, A. D. F, IV: 1
 Norris, J. F. F, I: 3
 Norton, A. E. F, I: 4
 Norton, C. L. F, I: 2
 Nourse, E. G. F, III: 3
 Noyes, A. A. F, I: 3
 Noyes, G. R. F, IV: 3
 Noyes, W. A. F, I: 3
 Noyes, W. A., Jr. F, I: 3
 Nuttall, G. H. F. FHM, II: 3
 d'Ocagne, M. FHM, I: 4
 O'Connell, W. H. F, IV: 1
 O'Connor, J. F, IV: 1
 Oertel, H. FHM, IV: 3
 Ogburn, W. F. F, III: 3
 Oldenberg, O. F, I: 2
 Oldfather, W. A. F, IV: 3
 Olmsted, F. L. F, I: 4
 Osborn, H. F. F, II: 3
 Osgood, R. B. F, II: 4
 Osterhout, W. J. V. F, II: 2
 Page, C. H. F, IV: 4
 Page, L. F, I: 2
 Palache, C. F, II: 1
 Paneth, F. FHM, I: 3
 Park, C. E. F, IV: 1
 Park, C. F. F, I: 4
 Park, R. E. F, III: 3
 Parker, G. H. F, II: 3
 Parker, H. F, III: 1
 Parks, L. F, IV: 1
 Parry, M. F, IV: 3
 Paschen, F. FHM, I: 2
 Patch, H. R. F, IV: 3
 Peabody, F. G. F, IV: 1
 Pearl, R. F, II: 3
 Pearse, L. F, I: 4
 Pearson, K. FHM, IV: 2

- Pease, A. S. F, IV: 3
 Peers, E. A. FHM, IV: 4
 Peirce, G. J. F, II: 2
 Pender, H. F, I: 4
 Pepper, G. W. F, III: 1
 Perkins, T. N. F, III: 4
 Persons, W. M. F, III: 3
 Peters, A. J. F, III: 4
 Pfeiffer, R. H. F, IV: 2
 Phelps, W. L. F, IV: 4
 Phillips, H. B. F, I: 1
 Phillips, J. C. F, II: 3
 Philpott, A. J. F, IV: 4
 Picard, C. E. FHM, I: 1
 Pickard, G. W. F, I: 4
 Pickering, W. H. F, I: 1
 Pidal, R. M. FHM, IV: 3
 Pierce, G. W. F, I: 2
 Pigou, A. C. FHM, III: 3
 Pilsbry, H. A. F, II: 3
 Pirenne, H. FHM, IV: 2
 Planck, M. FHM, I: 2
 Pollock, Sir F. FHM, III: 1
 Poor, C. L. F, I: 1
 Post, C. R. F, IV: 4
 Pound, R. F, III: 1
 Prandtl, L. FHM, I: 4
 Pratt, C. C. F, IV: 1
 Pratt, F. H. F, II: 3
 Pratt, J. H. F, II: 4
 Prescott, S. C. F, I: 3
 Probst, E. FHM, I: 4
 Pupin, M. I. F, I: 2
 Putnam, H. F, III: 4
 Quinby, W. C. F, II: 4
 Rabaud, H. FHM, IV: 4
 Rand, E. K. F, IV: 3
 Rand, H. W. F, II: 3
 Rapport, D. F, II: 3
 Raymond, P. E. F, II: 1
 Reading, Lord. FHM, III: 4
 Redfield, A. C. F, II: 3
 Redlich, J. FHM, III: 1
 Regan, C. T. FHM, II: 3
 Rehder, A. F, II: 2
 Reisner, G. A. F, IV: 2
 Rendle, A. B. FHM, II: 2
 Renner, O. FHM, II: 2
 Richards, A. N. F, II: 3
 Richards, R. H. F, I: 3
 Richardson, R. G. D. F, I: 1
 Riddle, O. F, II: 3
 Ripley, A. L. F, III: 4
 Rist, C. FHM, III: 3
 Ritter, W. E. F, II: 3
 Robinson, B. L. F, II: 2
 Robinson, D. M. F, IV: 2
 Robinson, E. A. F, IV: 4
 Robinson, F. N. F, IV: 3
 Rogers, A. F. F, II: 1
 Root, E. F, III: 1
 Root, R. K. F, IV: 3
 Rosanoff, M. A. F, I: 3
 Rosenau, M. J. F, II: 4
 Ross, D. W. F, IV: 4
 Rossby, C. G. A. F, II: 1
 Rostovtzeff, M. I. F, IV: 2
 Rowe, L. S. F, III: 3
 Rugg, A. P. F, III: 1
 Ruggles, A. H. F, II: 4
 Russell, G. E. F, I: 4
 Russell, H. N. F, I: 1
 Rutherford, Baron. FHM, I: 2
 Ruthven, A. G. F, II: 3
 Rutledge, G. F, I: 1
 Ryan, J. H. F, IV: 1
 Sachs, P. J. F, IV: 4
 Sapir, E. F, IV: 2
 Sarton, G. F, IV: 2
 Saunders, F. A. F, I: 2
 Sauveur, A. F, I: 4
 Sax, K. F, II: 2
 Sayles, R. W. F, II: 1
 Sayre, F. B. F, III: 1
 Scatchard, G. F, I: 3
 Schaller, W. T. F, II: 1
 Schell, E. H. F, III: 4
 Schevill, R. F, IV: 3
 Schlesinger, F. F, I: 1
 Schuchert, C. F, II: 1
 Schumb, W. C. F, I: 3
 Schumpeter, J. A. F, III: 3

- Scott, A. W. F, III: 1
 Scott, W. B. F, II: 1
 Sedgwick, E. F, IV: 4
 Sedgwick, H. D. F, IV: 4
 Sellards, A. W. F, II: 4
 Setchell, W. A. F, II: 2
 Seward, A. C. FHM, II: 2
 Shapley, H. F, I: 1
 Shattuck, F. C. F, II: 4
 Shaw, Sir W. N. FHM, II: 1
 Shear, T. L. F, IV: 2
 Shepley, H. R. F, IV: 4
 Sherrill, H. K. F, IV: 1
 Sherrill, M. S. F, I: 3
 Sherrington, Sir C. S. FHM, II: 4
 Shimer, H. W. F, II: 1
 Sinnott, E. W. F, II: 2
 Slater, J. C. F, I: 2
 Slipper, V. M. F, I: 1
 Slocum, F. F, I: 1
 Smith, D. S. F, IV: 4
 Smith, G. M. F, II: 2
 Smith, H. E. F, IV: 3
 Smith, H. M. F, I: 3
 Smith, J., Jr. F, III: 4
 Smith, L. B. F, I: 3
 Smith, P. F, III: 4
 Smyth, H. L. F, I: 4
 Smyth, H. W. F, IV: 3
 Snyder, C. F, III: 3
 Snyder, V. F, I: 1
 Sørensen, S. P. L. FHM, I: 3
 Sollmann, T. H. F, II: 4
 Sombart, W. FHM, III: 3
 Sorokin, P. A. F, III: 3
 Spemann, H. FHM, II: 3
 Sperry, W. L. F, IV: 1
 Spinden, H. J. F, IV: 2
 Spofford, C. M. F, I: 4
 Sprague, O. M. W. F, III: 3
 Stafford, R. H. F, IV: 1
 Stakman, E. C. F, II: 2
 Stammler, R. FHM, II: 1
 Stamp, Sir J. FHM, III: 4
 Stearns, A. W. F, III: 4
 Stebbins, J. F, I: 1
 Stein, Sir A. FHM, IV: 2
 Stephenson, F. B. F, IV: 3
 Stetson, H. T. F, I: 1
 Stevens, J. F. F, I: 4
 Stieglitz, J. O. F, I: 3
 Stiles, C. W. F, II: 4
 Stiles, P. G. F, II: 3
 Stodola, A. FHM, I: 4
 Stone, H. F. F, III: 1
 Stone, J. S. F, I: 2
 Stone, M. H. F, I: 1
 Strong, R. P. F, II: 4
 Struik, D. J. F, I: 1
 Struve, P. B. FHM, III: 3
 Sumner, J. O. F, IV: 2
 Taber, H. F, I: 1
 Talbot, F. B. F, II: 4
 Tamarkin, J. D. F, I: 1
 Tarbell, E. C. F, IV: 4
 Taussig, F. W. F, III: 3
 Taylor, C. H. F, III: 4
 Taylor, C. H. F, IV: 2
 Taylor, F. B. F, II: 1
 Teggart, F. J. F, III: 3
 Terman, L. M. F, IV: 1
 Terry, C. S. FHM, IV: 2
 Theiler, Sir A. FHM, II: 4
 Thomas, F. W. FHM, IV: 3
 Thomas, W. I. F, III: 3
 Thompson, D'A. W. FHM, II: 3
 Thompson, M. deK. F, I: 2
 Thomson, E. F, I: 2
 Thomson, Sir J. J. FHM, I: 2
 Thomson, W. F, IV: 3
 Thorndike, E. L. F, IV: 1
 Thurston, E. S. F, III: 1
 Thwing, C. F. F, III: 4
 Timonoff, V. E. FHM, I: 4
 Tolman, R. C. F, I: 3
 Torrey, C. C. F, IV: 2
 Tozzer, A. M. F, IV: 2
 Trelease, W. F, II: 2
 Trevelyan, G. M. FHM, IV: 2
 Tucker, D. S. F, III: 3
 Tyler, H. W. F, I: 1
 Tyzzer, E. E. F, II: 4

- Usher, A. P. F, III: 3
 Vallarta, M. S. F, I: 2
 Vallée Poussin, C. J. de la. FHM, I: 1
 Van Vleck, J. H. F, I: 2
 Vaughan, T. W. F, II: 1
 Veblen, O. F, I: 1
 Vecchio, G. Del. FHM, III: 1
 Verhoeff, F. H. F, II: 4
 Viner, J. F, III: 3
 Vries, H. de. FHM, II: 2
 Wagner, K. W. FHM, I: 4
 Wat, W. C. F, III: 1
 Walker, C. H. F, IV: 4
 Walsh, J. L. F, I: 1
 Wambaugh, E. F, III: 1
 Warner, E. P. F, I: 4
 Warren, C. H. F, II: 1
 Washburn, H. B. F, IV: 1
 Watson, J. B. F, IV: 1
 Wearn, J. T. F, II: 4
 Weatherby, C. A. F, II: 2
 Webster, D. L. F, I: 2
 Webster, E. S. F, III: 4
 Weiss, S. F, II: 4
 Wells, A. E. F, I: 4
 Wells, F. L. F, IV: 1
 Weston, G. B. F, IV: 3
 Weston, R. S. F, I: 4
 Weston, W. H. F, II: 2
 Wetmore, R. H. F, II: 2
 Weyl, H. FHM, I: 1
 Weyssse, A. W. F, II: 3
 Whatmough, J. F, IV: 3
 Wheeler, W. M. F, II: 3
 White, B. F, II: 4
 White, D. F, II: 1
 Whitehead, A. N. F, I: 1
 Whitlock, H. P. F, II: 1
 Whitman, E. A. F, III: 1
 Whitney, W. R. F, I: 3
 Wickersham, G. W. F, III: 1
 Widder, D. V. F, I: 1
 Wieland, H. FHM, I: 3
 Wilkins, E. H. F, IV: 3
 Williams, F. H. F, II: 4
 Williams, J. H. F, III: 3
 Williams, R. S. F, I: 3
 Willis, B. F, II: 1
 Willoughby, W. F. F, III: 2
 Willoughby, W. W. F, III: 2
 Willstätter, R. FHM, I: 3
 Wilson, E. B. F, II: 3
 Wilson, E. B. F, I: 2
 Wilson, G. G. F, III: 2
 Winsor, F. E. F, I: 4
 Wissler, C. F, IV: 2
 Wister, O. F, IV: 4
 Wolbach, S. B. F, II: 4
 Wolff, J. E. F, II: 1
 Wolfson, H. A. F, IV: 3
 Wolman, L. F, III: 3
 Wood, R. W. F, I: 2
 Woodman, A. G. F, I: 3
 Woods, F. A. F, II: 3
 Woods, F. S. F, I: 1
 Worcester, J. R. F, I: 4
 Worrall, D. E. F, I: 3
 Wright, C. H. C. F, IV: 4
 Wright, F. E. F, II: 1
 Wright, Q. F, III: 2
 Wroth, L. C. F, IV: 2
 Wyman, J., Jr. F, II: 3
 Yeomans, H. A. F, III: 2
 Yerkes, R. M. F, IV: 1
 Young, B. L. F, III: 4
 Young, K. F, IV: 3
 Zeleny, J. F, I: 2
 Zimmerman, C. C. F, III: 3
 Zinsser, H. F, II: 4

STATUTES AND STANDING VOTES.

STATUTES.

Adopted November 8, 1911: amended May 8, 1912, January 8, and May 14, 1913, April 14, 1915, April 12, 1916, April 10, 1918, May 14, 1919, February 8, April 12, and December 13, 1922, February 14, March 14, and October 10, 1923, March 10, 1926, May 9, 1928, April 8 and November 11, 1931, April 12, 1933, and February 14, 1934.

CHAPTER I.

THE CORPORATE SEAL.

ARTICLE 1. The Corporate Seal of the Academy shall be as here depicted:



ARTICLE 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3: chap. vi, art. 2.

CHAPTER II.

FELLOWS AND FOREIGN HONORARY MEMBERS AND DUES.

ARTICLE 1. The Academy consists of Fellows, who are either citizens or residents of the United States of America, and Foreign Honorary Members. They are arranged in four Classes, according to the Arts and Sciences in which they are severally proficient, and each Class is divided into four Sections, namely:

CLASS I. *The Mathematical and Physical Sciences*

- Section 1. Mathematics and Astronomy
- Section 2. Physics
- Section 3. Chemistry
- Section 4. Technology and Engineering

CLASS II. *The Natural and Physiological Sciences*

- Section 1. Geology, Mineralogy, and Physics of the Globe
- Section 2. Botany
- Section 3. Zoölogy and Physiology
- Section 4. Medicine and Surgery

CLASS III. *The Social Arts*

- Section 1. Jurisprudence
- Section 2. Government, International Law, and Diplomacy
- Section 3. Economics and Sociology
- Section 4. Administration and Affairs

CLASS IV. *The Humanities*

- Section 1. Theology, Philosophy, and Psychology
- Section 2. History, Archæology, and Anthropology
- Section 3. Philology
- Section 4. The Fine Arts and Belles Lettres

ARTICLE 2. The number of Fellows shall not exceed Eight hundred, of whom not more than Six hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and twenty in any one Class.

ARTICLE 3. The number of Foreign Honorary Members shall not exceed One hundred and thirty. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and

attainments in any of the Classes above enumerated. There shall not be more than Thirty-five in any one Class.

ARTICLE 4. If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or, if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow; but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii, art. 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars, unless previously as an Associate he has paid an Admission Fee of like amount.

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments. Any Fellow shall also be exempt from Annual Dues who has paid such dues

for forty years, or, having attained the age of seventy-five has paid dues for twenty-five years.

All Commutations of the Annual Dues shall be and remain permanently founded, the interest only to be used for current expenses.

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease; but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

ARTICLE 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all Publications of the Academy issued after their election.

See Chap. xi, art. 2.

ARTICLE 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretaries, shall be given to Foreign Honorary Members and to Fellows on request.

ARTICLE 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii; chap. vi, art. 1; chap. x, art. 1, 7; chap. xi, art. 2.

CHAPTER III.

ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS.

The procedure in the election of Fellows and Foreign Honorary Members shall be as follows:

Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by Two Fellows of that Section, or by three Fellows of any Sections, and sent to the Corresponding Secretary ac-

accompanied by a statement of the qualifications of the nominee and brief biographical data.

Notice shall be sent to every Fellow not later than the fifteenth of January in each year, reminding him that all nominations must be in the hands of the Corresponding Secretary before the fifteenth of February following.

A list of the nominees, giving a brief account of each, with the names of the nominators, shall be sent to every Fellow with a request that he return the list with such confidential comments and indications of preference as he may choose to make.

All the nominations, with any comments thereon and with expressions of preference on the part of the Fellows, shall be referred to the appropriate Class Committees, which shall canvass them, and report their recommendations in writing to the Council before the Stated Meeting of the Academy in April.

Elections of Fellows and Foreign Honorary Members shall be made by the Council before the Annual Meeting in May, and announced at that meeting.

Persons nominated in any year, but not elected, may be carried over to the list of nominees for the next year at the discretion of the Council, but shall not be further continued unless renominated.

See Chap. ii; chap. vi, art. 1; chap. x, art. 1.

CHAPTER IV.

OFFICERS.

ARTICLE 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), four Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also sixteen Councillors, one from each Section of each Class. At each Annual Meeting four Councillors, one from each Class, shall be elected by ballot to serve for the full term of four years and until others are duly chosen and installed. The same Fellow shall not be eligible for two successive terms.

The Councillors, with the other officers previously named, and the Chairman of the House Committee, *ex officio*, shall constitute the Council.

See Chap. xi, art. 1.

ARTICLE 2. If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of four Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap. vi, art. 2.

ARTICLE 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap. vi, art. 2.

ARTICLE 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V.

THE PRESIDENT.

ARTICLE 1. The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous Fellowship in the Academy), shall preside at all meetings of the Academy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

ARTICLE 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii, art. 7; chap. iv, art. 1, 3; chap. vi, art. 2; chap. vii, art. 1; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1.

CHAPTER VI.

THE SECRETARIES.

ARTICLE 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. He shall also notify all meetings of the Council; and in case of the death, absence, or inability of the Recording Secretary he shall notify all meetings of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap. ii, art. 7; chap. iii; chap. iv, art. 1; chap. x, art. 6; chap. xi, art. 1; chap. xii, art. 1.

ARTICLE 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

Fellows borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and by

mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. iv, art. 3.

In the absence of the President and of the Vice-Presidents he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i; chap. ii, art. 7; chap. iv, art. 3, 4, 5; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1, 3.

ARTICLE 3. The Secretaries, with the Editor, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII.

THE TREASURER AND THE TREASURY.

ARTICLE 1. The Treasurer shall collect all money due or payable to the Academy, and all gifts and bequests made to it. He shall pay all bills due by the Academy, when approved by the proper officers, except those of the Treasurer's office, which may be paid without such approval; in the name of the Academy he shall sign all leases of real estate; and, with the written consent of a member of the Committee on Finance, he shall make all transfers of stocks, bonds, and other securities belonging to the Academy, all of which shall be in his official custody.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the Appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

ARTICLE 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

ARTICLE 3. He shall give such security for the trust reposed in him as the Academy may require.

ARTICLE 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

ARTICLE 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

ARTICLE 6. The Financial Year of the Academy shall begin with the first day of April.

ARTICLE 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council.

See Chap. ii, art. 4, 5; chap. vi, art. 2; chap. x, art. 6; chap. xi, art. 1, 2, 3; chap. xii, art. 1.

CHAPTER VIII.

THE LIBRARIAN AND THE LIBRARY.

ARTICLE 1. The Librarian shall have charge of the printed books, keep a correct catalogue thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

ARTICLE 2. In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

ARTICLE 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

ARTICLE 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

ARTICLE 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the remainder of the set, if any, shall be delivered to the Fellow so paying, unless such remainder be valuable by reason of association.

ARTICLE 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

ARTICLE 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii, art. 6; chap. xi, art. 1, 2.

CHAPTER IX.

THE EDITOR AND THE PUBLICATIONS.

ARTICLE 1. The Editor shall have charge of the conduct through the press of the Proceedings and the Memoirs, and all correspondence relative thereto, and shall have power to fix the price at which individual numbers of the Proceedings and Memoirs are sold.

ARTICLE 2. In conjunction with the Committee of Publication, he shall have authority to expend such sums as may be appropriated by the Academy for printing the publications and for defraying other expenses therewith connected.

ARTICLE 3. All publications which are financed in whole or in part from the income of the Rumford Fund or from the income of other

special funds, and all publications of work done with the aid of the Rumford Fund or other special funds, shall contain a conspicuous statement of this fact.

ARTICLE 4. Two hundred extra copies of each paper printed in the Proceedings or Memoirs shall be placed at the disposal of the author without charge.

If, on account of the number of communications offered for publication, it shall be necessary to decline for publication communications otherwise acceptable, members of the Academy shall be given preference in each of the several Classes over non-members; but whenever it shall be necessary to exercise this preference, the Editor shall inform the Council of the fact.

See Chap. iv, art. 1; chap. vi, art. 3; chap. x, art. 6; chap. xi, art. 4.

CHAPTER X.

THE COUNCIL.

ARTICLE 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and act upon them in accordance with the provisions of Chapter III.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections, reporting its action to the Academy.

See Chap. iii, art. 2, 3; chap. xi, art. 1.

ARTICLE 2. Nine members shall constitute a quorum.

ARTICLE 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

ARTICLE 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

ARTICLE 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

ARTICLE 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Committees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Academy, or at a Special Meeting called for the purpose.

See Chap. xi, art. 3.

ARTICLE 7. After the death of a Fellow or Foreign Honorary Member, it shall appoint a member of the Academy to provide a biographical notice for publication in the Proceedings.

ARTICLE 8. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap. ii, art. 4, 5, 8; chap. iv, art. 1, 2; chap. vi, art. 1; chap. vii, art. 1; chap. xii, art. 1, 4.

CHAPTER XI.

STANDING COMMITTEES.

ARTICLE 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship

in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap. iii, art. 2.

ARTICLE 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year:

(i) *The Committee on Finance*, to consist of four Fellows, who, through the Treasurer, shall have full control and management of the funds and trusts of the Academy, with the power of investing the funds and changing the investments thereof in their discretion.

See Chap. iv, art. 3; chap. vii, art. 1, 4; chap. x, art. 6.

(ii) *The Rumford Committee*, to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iii) *The Cyrus Moors Warren Committee*, to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iv) *The Committee of Publication*, to consist of the Editor, *ex officio*, as Chairman, and four other Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted.

It shall fix the price at which volumes of the publications shall be sold; but Fellows may be supplied at half price with volumes which they are not entitled to receive gratis.

It shall determine when the pressure of material offered for publication makes it necessary to give preference to members of the Academy as compared with non-members, or to give priority to certain members as compared with others, and to what extent this preference or priority shall be applied in each of the four Classes, to the

end that a proper balance of the facilities of publication with respect to subject matter and authors may be maintained.

See Chap. iv, art. 3; chap. vi, art. 1, 3; chap. ix; chap. x, art. 6.

(v) *The Committee on the Library*, to consist of the Librarian, *ex officio*, as Chairman, and four other Fellows, one from each Class, who shall examine the Library and make an annual report on its condition and management.

See Chap. iv, art. 3; chap. viii, art. 1, 2; chap. x, art. 6.

(vi) *The House Committee*, to consist of four Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv, art. 1, 3; chap. x, art. 6.

(vii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and four other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv, art. 3; chap. x, art. 6.

(viii) *The Auditing Committee*, to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap. iv, art. 3; chap. vii, art. 1; chap. x, art. 6.

(ix) *The Committee on Biographical Notices*, to consist of six Fellows, two to be elected each year, six in 1933, one of them to be a Secretary of the Academy, to see that biographical notices of the Fellows are provided.

See Chap. x, art. 7.

ARTICLE 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen.

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii, art. 1, 7; chap. x, art. 6.

CHAPTER XII.

MEETINGS, COMMUNICATIONS, AND AMENDMENTS.

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

A meeting for receiving and discussing literary or scientific communications may be held on the fourth Wednesday of each month, excepting July, August, and September; but no business shall be transacted at said meetings.

ARTICLE 2. Twenty-five Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Eighteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4. No report of any paper presented at a meeting of the Academy shall be published by any Fellow without the consent of the author; and no report shall in any case be published by any Fellow in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members.

ARTICLE 5. No Fellow shall introduce a guest at any meeting of the Academy until after the business has been transacted, and especially until after the result of the balloting upon nominations has been declared.

ARTICLE 6. The Academy shall not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its Publications.

ARTICLE 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two-thirds of the ballot cast, and not less than twenty-five, must be affirmative to effect enactment.

ARTICLE 8. Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two-thirds of the members present. They may be suspended by a unanimous vote.

See Chap. ii, art. 5, 8; chap. iii; chap. iv, art. 3, 4, 5; chap. v, art. 1; chap. vi, art. 1, 2; chap. x, art. 8.

STANDING VOTES.

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4. The Council, under such rules respecting nominations as it may prescribe, may elect as Associates of the Academy a limited number of men of mark in affairs or of distinguished service in the community.

Associates shall be entitled to the same privileges as Fellows, but shall not have the right to vote.

The admission fee and annual dues of Associates shall be the same as those of Fellows residing within fifty miles of Boston.

5. Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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